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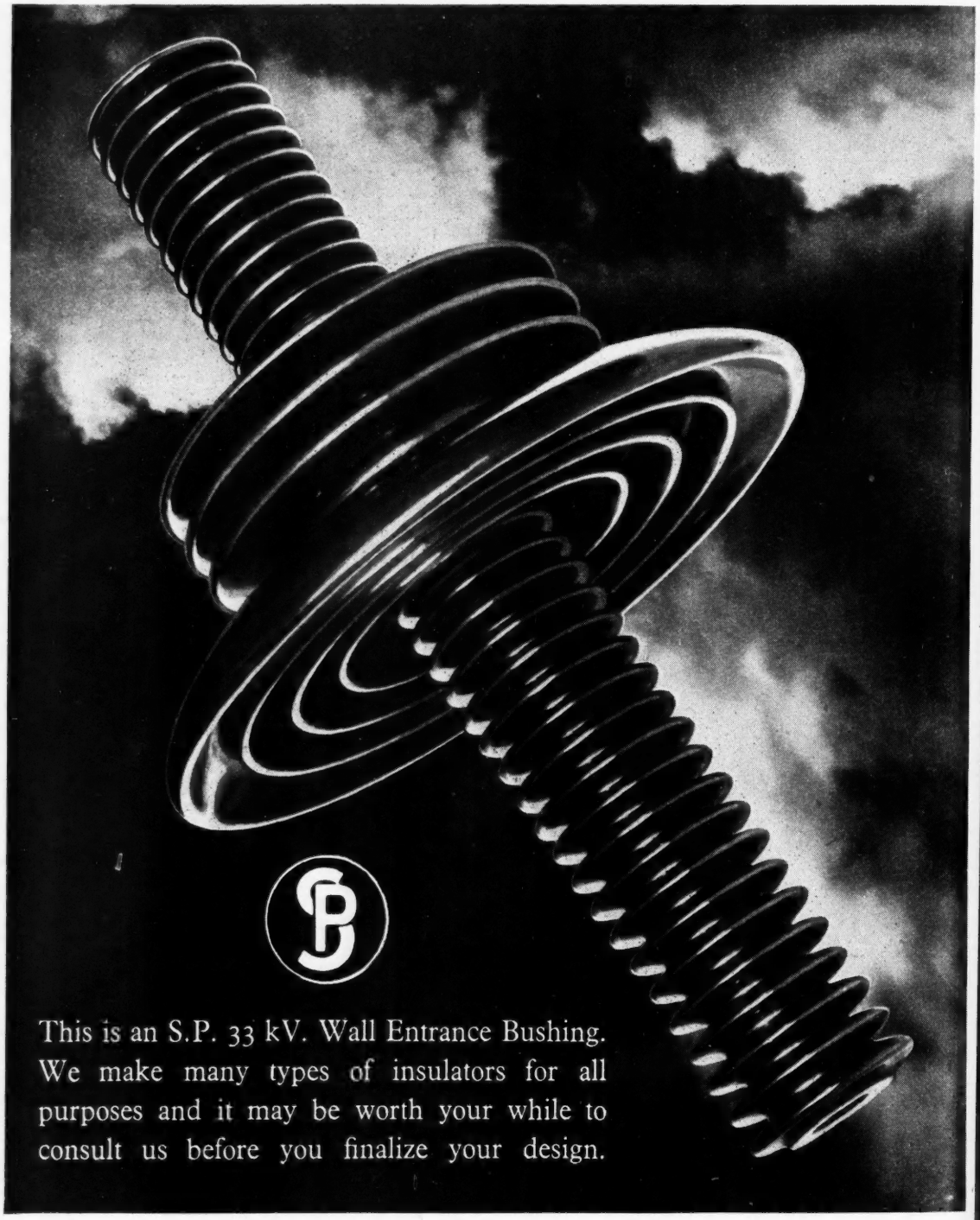
Electronic Engineering

INCORPORATING ELECTRONICS, TELEVISION AND SHORT WAVE WORLD

PRINCIPAL CONTENTS

The C.R. Tube in Mechanical Testing
Before the Diode
Simplifying Symbols
Aerial Characteristics (Data Sheet)—Part 4
H.F. Therapy—Part 4

2/- DEC., 1943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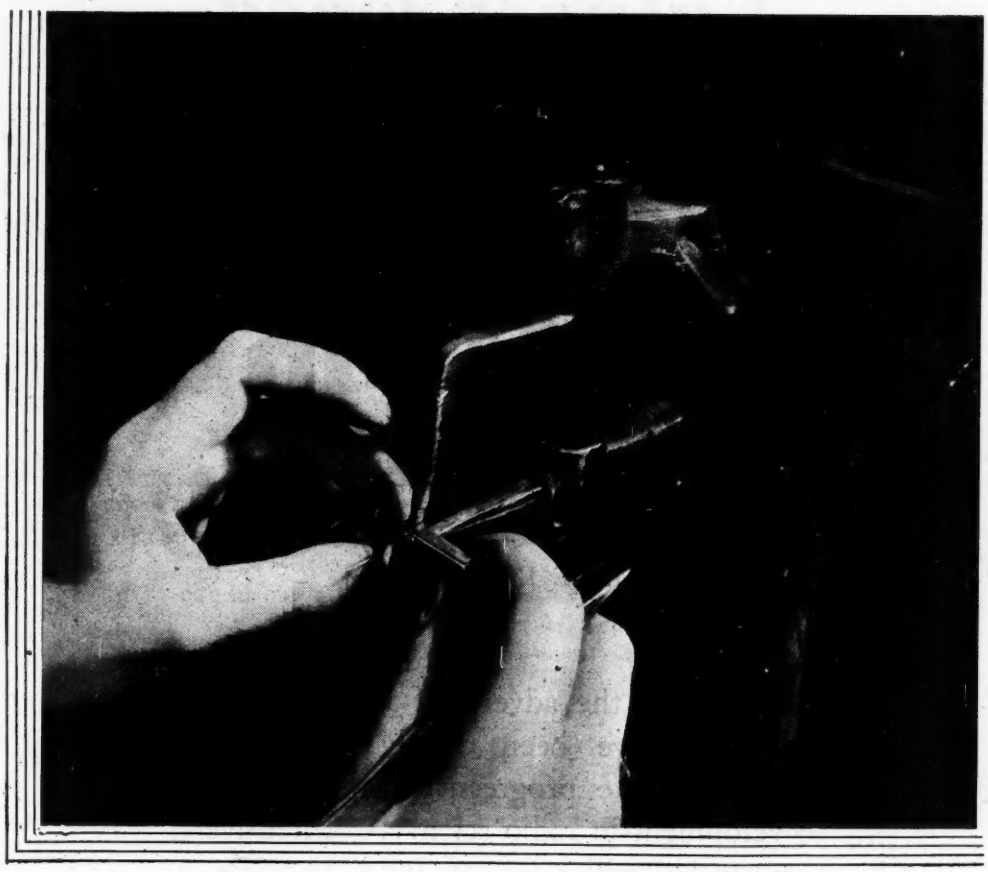

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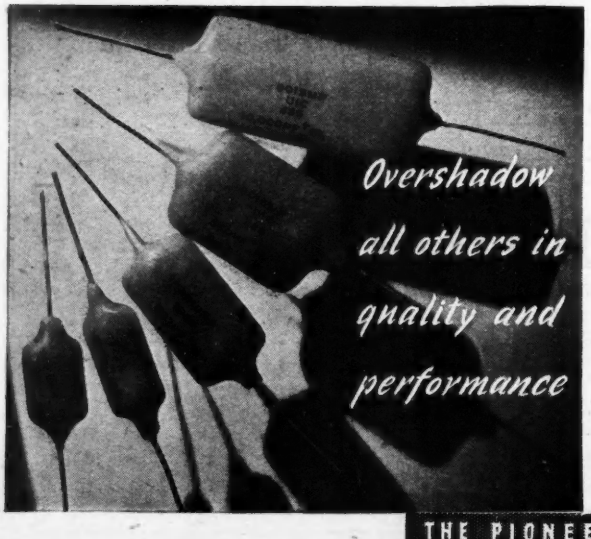

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Electronic Engineering

DECEMBER, 1943

Volume XVI. **No. 190.**

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Research

THE report of the Parliamentary and Scientific Committee, published in October last*, should be read by all interested in the future of research in this country.

The Committee was composed of an unofficial group of members of both Houses and representatives of certain scientific and technical institutions, and their report is divided into two parts: (1) the Need for Increased Research; (2) The Supply and Training of Research Personnel.

In reading through the first part one is struck by the comparisons between this country and the U.S.A. or U.S.S.R. in research expenditure. In 1938–39 the total research expenditure in this country was approximately £7,000,000. It is estimated that the corresponding amount spent in the U.S.A. was ten times this—£70,000,000, and the outlay in Russia is on a similar scale.

Some of the figures given for Government grants are so low that they read like misprints. The Royal Society administers a Government Grant-in-Aid for Scientific Investigations of no less than £7,000 per annum. The Parliamentary Grant-in-Aid for Scientific Publication amounts to £2,500 p.a. for the Royal Society and the Royal Society of Edinburgh combined. The Committee remark mildly that "provision should be made for a considerable increase of this Grant."

The recommendations in the latter part of the report are concerned mainly with improvements in the University training for research, in increased teaching staffs, and the development of technical education.

The universities will have to prepare for a rapid growth in the number of students, and this will call for an expansion of existing universities and the development of some existing establishments into new universities.

University staffs, stipends, and buildings will all require to be increased and it is suggested that a capital sum of £10,000,000 will be required over the first five post-war years.

The present Treasury grant of £2,250,000 p.a. should be increased to at least £6,000,000 . . . . and so on.

It is gratifying that the salary of university teachers receives special mention. The average salary of all grades of lecturers in universities other than Oxford or Cambridge was £313 p.a. at the age of 30. Agreed, this salary is in most cases supplemented by examination fees or coaching fees, but why should the lecturer be compelled to work overtime to earn an adequate income?

An interesting point for radio engineers is that there have been recommendations made for the formation of a Radio Research Board on the lines of the Electrical Research Board.

It is recognised that the majority of leading manufacturers already have extensive and well-equipped laboratories, but the establishment of a central research institute cannot fail to benefit the industry as a whole. It will certainly tend to avoid duplication of effort, which is a characteristic of many separate research centres. If the industry supports it more handsomely than the Government support their own establishments in peace-time, it will ensure that we do not resume a back seat in post-war radio and television.

* Obtainable from the Parliamentary and Scientific Committee, Courtfield House, Courtfield Road, London, S.W.7., price 1s.

ELECTRONIC MUSIC GROUP

NOTICE

A preliminary meeting to discuss the formation and future activities of the Electronic Music Group will be held on

Saturday, January 8th, 1944

at 2.30 p.m., at the

Northern Polytechnic, Holloway Road, N., by kind permission of the Head of the Music Trades Dept.

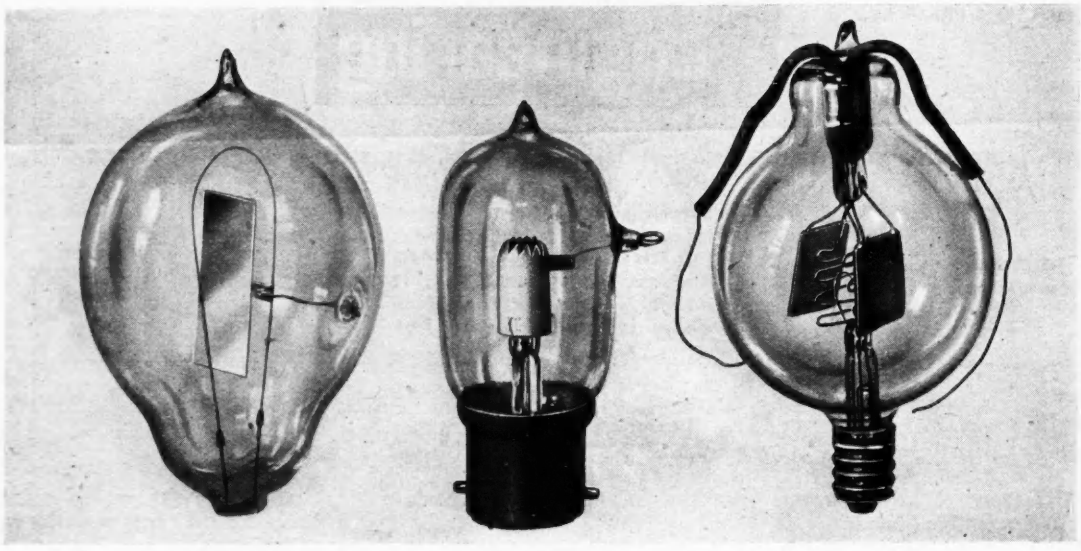
Any reader interested in the subject is invited to attend, in addition to those whose names have already been registered with this journal.

Nearest Tube Station: Holloway Road (Piccadilly Line).

Trolley Buses 609 and 611 pass the door. Bus: 43.

THE DIODE AND AFTER

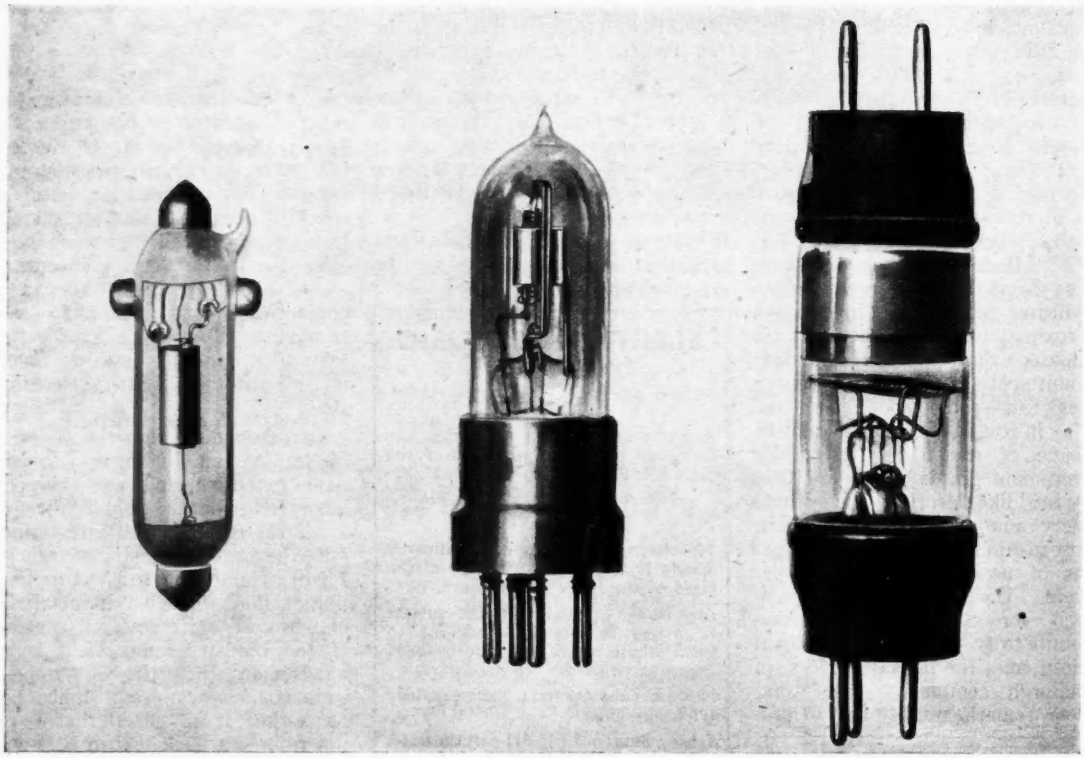
Some Landmarks in Valve Development



Fleming's original Diode of 1904

Later type of commercial diode

de Forest's Audion



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Before the Diode

Under the title "The Saga of the Vacuum Tube" Mr. G. F. J. Tyne has contributed a series of articles to the American journal "*Radio News*". This extract deals with developments prior to the discovery of the Edison Effect and the Fleming Diode, and is reproduced by permission of the author and publishers. The series is being published in book form in due course and will constitute a well-documented account of the history and development of the thermionic valve

IN 1851 Professor Heinrich Buff, of the University of Geissen, published a paper[1] on the electrical conditions existing in flames. He came to the conclusion that gaseous bodies which have been rendered conductive by strong heating are capable of exciting other conductors, solid as well as gaseous, electrically. At that time the incandescent lamp was far in the future, and the experiments reported were made using two small strips of platinum introduced into a glass tube which was closed at one end. Experiments involving heating the tube even to the softening point of the glass gave a negative result, but when the strips of platinum were exposed to the direct action of the flame of a spirit lamp, a current flowed between the strips, the flow being from the hotter of the two strips toward the colder.

Edward Becquerel, illustrious son of an illustrious father, in 1853 began a study of the electrical conductivity of gases. His method was to apply heat externally to a platinum tube, down the axis of which were stretched two parallel platinum wires, maintained at a difference of potential by a low voltage battery. This procedure was varied in some cases by using the tube as one electrode and a platinum rod placed axially in the tube, and supported at one end, as the other electrode. From his experiments with this apparatus, and the measuring equipment which had been developed by the work of the men of whom we have previously spoken, he came to the following conclusions: [2, 3, 4].

(1) Gases become conductors only at or above the temperature corresponding to red heat, and as the temperature increases so does the conductivity.

(2) At such temperatures they are conductors even when a low voltage is applied.

(3) The relative dimensions of the electrodes have an effect on the conductivity of the gas, the conductivity increasing rapidly with the surface of the negative electrode.

(4) The resistance of the gas varies with the applied voltage, and with the current through it, that is, it does not obey Ohm's law.

(5) Below red heat the pressure of the gas has little effect, there being no conduction at low voltages. Above red heat rarefaction of the gas increases the conductivity.

We know now that these effects noted by Becquerel were due not alone to the fact that the gas was heated, tending to produce ionic conductivity, but also to the fact that the electrodes were heated, whereby thermionic emission was taking place. The results obtained by Becquerel do not seem to be widely known, as little credit is given to him in later treatises on the conduction of electricity through gases.

Gustav Wiedemann refused to concede the possibility of gaseous conduction and attempted[5] to explain away Becquerel's results by attributing them to changes in the conductivity of the cement used in sealing the electrodes in place. Blondlot, in 1881, confirmed[6] the results of Becquerel and disproved the contention of Wiedemann.

Fredrick Guthrie, in 1873, repeated Nollet's procedure of more than a century before, of heating iron white hot and testing it for discharging power as it cooled. He found[7] that at white heat an iron ball would retain neither a positive nor a negative charge of electricity, but that at red heat it could retain a negative charge, but not a positive one.

The Edison Effect

In 1879 Thomas A. Edison finally succeeded in "subdividing the electric light" when he brought the incandescent lamp to commercial practicability. He was still at work perfecting it some four years later, when he observed and recorded the phenomenon which received the name of the "Edison effect."

During his experiments he observed that as the time of operation of his incandescent lamp increased, the light output was reduced by a blackish deposit on the interior of the glass bulb.

In the course of his investigations he noted two other things which were of great importance. The first was that there was frequently to be found on the glass, in the plane of the filament, a line which was not blackened. The second, and this was the more important of the two, was that the leg of the filament which was connected to the positive pole of the circuit was always that which "cast the shadow." It appeared that the opposite side, which was connected to the negative pole, was throwing off minute particles of filament material which travelled outwards and were deposited on the glass everywhere except where the glass was screened by the positive leg of the filament.

In order to study this effect more in detail, Edison had constructed some lamp bulbs containing filaments and, in addition, small metallic shielding plates placed between the legs of the filament. He found[8] that if this plate was connected to the positive end of the filament a current would flow across the vacuous space, but that no current would flow if it were connected to the negative end.

Seemingly, the only use which Edison could imagine for this device was as an indicator to show variations of potential on the lighting circuit.

In his patent application,[9] filed November 15, 1883, for an "Electrical Indicator," the lamp apparatus used is shown in Fig. 1. In this application, however, there is to be found this very significant clause concerning the current across the vacuous space—"This current I have found to be proportional to the degree of incandescence of the conductor or the candle power of the lamp."

Probably because of the work involved in the introduction of the incandescent lighting system, Edison did not have time to carry on further experiments. Even had he done so, and evolved a "valve" he would have been at least ten years ahead of his time.

The publication of the "Edison effect" aroused interest in many places. In the first paper printed in the first volume of the *Transactions* of the American Institute of Electrical Engineers, Professor Edwin J. Houston gave "Notes on Phenomena in Incandescent Lamps." In this paper[10] Professor Houston referred to the "peculiar high vacuum phenomena observed by Mr. Edison in some of his incandescent lamps." He then went on:

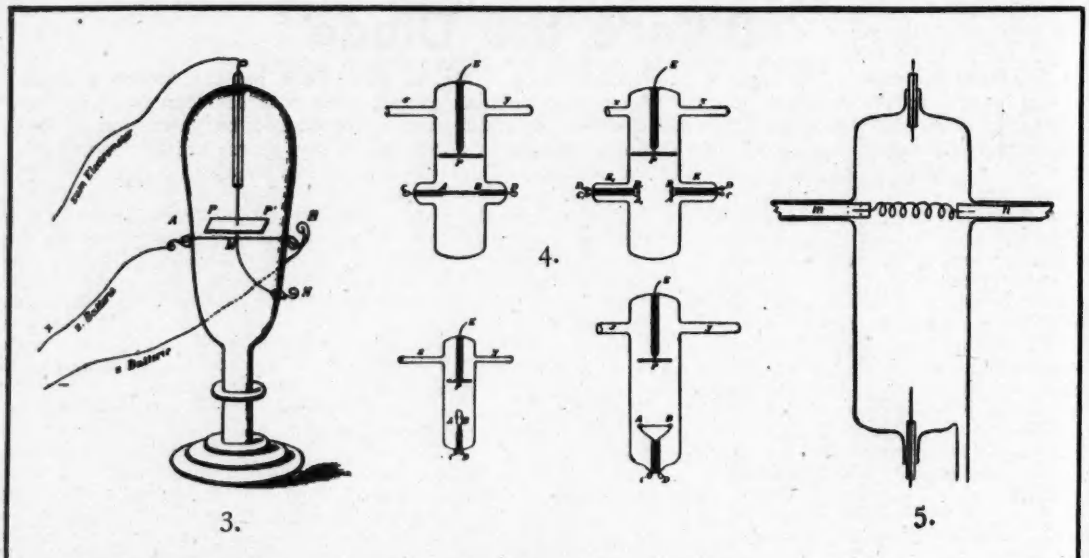

Fig. 3. Tube used by Elster and Geitel in 1887. Reproduced from "Annalen der Physik," 1887.

Fig. 4. Tubes used by Elster and Geitel to demonstrate unilateral conductivity. Reproduced from "Annalen der Physik," 1889.

Fig. 5. Tube used by Hittorf to demonstrate unilateral conductivity. Reproduced from "Annalen der Physik," 1884.

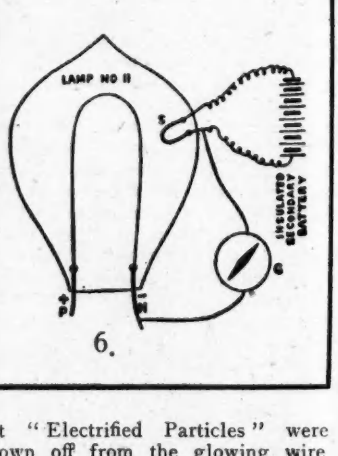

Fig. 6. Tube used by Fleming to demonstrate bi-directional conductivity as unidirectional conductivity. Reproduced from "Phil. Mag.", 1896.

"The question is, what is the origin of this current? How is it produced? Since we have within the globe nearly a complete vacuum, we cannot conceive the current as flowing across the vacuous space, as this is not in accordance with our preconceived ideas connected with high vacua."

Professor Houston described another of Mr. Edison's experiments which appeared to throw no little light on the matter. The apparatus used in this experiment is shown in Fig. 2 (which is Fig. 3 of Houston's paper). Instead of placing the cold electrode between the legs of the filament, as had previously been done, he placed two cold electrodes as shown at "P" and "P¹." Edison found that if the galvanometer was connected to the plate "P," as shown by the solid line, a current flowed through it, but that this was not the case when it was connected as shown by the dotted line, to "P¹." Apparently, the current could not flow around a corner.

Among those present, and taking an active part in the discussion which followed the reading of this paper was Sir William Preece, who was extremely interested in the new phenomena. He announced that he intended to exercise his persuasive eloquence upon Mr. Edison to induce Mr. Edison to give him one of these lamps and said:

"When I go back to England I shall certainly make an illustration before our society there, and then make careful inquiry into it."

How he succeeded and what he did will be seen later.

Let us now return for a while to Germany. Julius Elster and Hans Geitel, beginning about the year 1880, pursued a series of investigations in that country. The results of these researches were reported in a series of articles beginning in 1882. The first four of these articles[11] deal with the characteristics of flames, particularly with reference to their unsymmetrical conductivity, and in part confirm the earlier work done along these lines. The fifth article[12] which appeared in 1887 is entitled "On the Electrification of Gases by Glowing Bodies." In this article experiments were described involving the use of a glass bulb, which could be exhausted or filled with various gases. Across the inside of this bulb was stretched a platinum wire which could be heated electrically. *See* Fig. 3. Opposite this wire and very close to it, was placed a platinum plate suspended by a leading-out wire. The vacuum used was described as "the best possible—such as Crookes used in his famous experiments." The results of these experiments of Elster and Geitel indicated that "Electrified Particles" were thrown off from the glowing wire uniformly in every direction, and that the conductivity was unilateral.

The next paper,[13] published in 1889, is entitled "On the Excitation of Electricity when Galvanically Glowing Wires come in Contact with Heated Gases." In this paper various experiments were described involving the use of glowing platinum wires and glowing carbon filaments in exhausted bulbs, with cold electrodes of platinum placed at various distances from the glowing members. Mention is made of the fact that the carbon filament always excites the cold electrode negatively. The bulbs were so constructed that they could be placed within the poles of a magnet of the horse-shoe type, and the effect of the magnet on the apparent conductivity of the vacuous space was noted.

In the latter part of this paper a theory, first enunciated by A. Schuster,[14] is used to explain the unipolar conductivity. This theory is based on the dissociation of the gas molecules by contact with the glowing body. It is interesting to note that in this paper Elster and Geitel acknowledge that their work was made possible by a grant of American funds, provided by the Elizabeth Thompson Science Fund of Boston.

The last paper of this series was published[15] in 1889 and describes further experiments with various other tubes of the forms shown in Fig. 4.

While Elster and Geitel were conducting their investigations another German scientist, William Hittorf, had been for some time working on gaseous conduction. In his work Hittorf made use of high voltages, developed from a large number (2,400) Bunsen cells connected in series. This gave about 4,000-4,500 volts with which he could observe phenomena of the type seen in the days of static electricity, but which he could reproduce at will, and sustain long enough to permit of taking accurate observations. Hittorf's first paper "On the Conduction of Electricity in Gases," appeared[16] in 1869, his second[17] in 1874, his third[18] in 1879 and his fourth[19] in 1883. In these papers Hittorf describes his work on conduction in rarefied gases, using cold electrodes. It is in his fifth paper, which appeared[20] in 1884, that we first find reference to the use of a cathode which was heated by external means. The apparatus used is shown in Fig. 5. He was led to the use of this cathode by the difficulties he experienced with the evolution of gas from the electrodes previously used.

These electrodes became hot, owing to the high energies of the gaseous discharge and the occluded gases which were released impaired the vacuum and affected the discharge. To obviate this difficulty he used a cathode which could be maintained at a high temperature by means which were independent of the discharge. Hittorf's publications are dry, almost repulsive, reading and their value was buried deep in the mass of experimental data which he reported.

The experiments which he performed were essentially those of Becquerel, except that he used higher voltages and better vacua and was able to heat one electrode at a time. He observed that when the spiral platinum cathode was brought to or above a red heat, the conductivity of the gaseous space rose rapidly with the increase of cathode temperature, and that a similar condition was observed if the cathode were made of carbon. He noted[21] (as Becquerel had previously done) that the conductivity increased as the pressure of the gas was lowered.

He also noted that even with the cathode heated by means of an external auxiliary battery it was necessary, in order to maintain the vacuum, to continuously remove, by means of the pump, the gases given off. He observed that the current flowed only when the heated electrode was used as a cathode, at low voltages, that is, that the conductivity of the space was unilateral at those voltages. In this he went a step further than Becquerel, who could not have made such an observation since, due to his experimental arrangement, both his electrodes were heated.

Having thus followed the progress of investigation in Germany up to about 1890, let us now return to England. Early in 1882, after the formation of the Edison Electric Light Company of London, John Ambrose Fleming (later Sir John Ambrose Fleming) was appointed electrical adviser to the company. He was thus brought into close touch with the many problems which arose in the use of incandescent lamps. He, like Edison, soon noted that when carbon lamps were blackened in service there sometimes was found on the glass, at a point opposite where the filament had finally burned out, a lighter deposit of the black material than was to be seen elsewhere on the glass.

This he termed a "Molecular Shadow." His first mention of it comes in a paper read before the Physical Society of London on May 26, 1883.[22] In this paper he observes that the shadow is found only where there is a copper deposit on the inner surface of the glass bulb, never with the ordinary carbon deposit. This paper was a short one, more or less of a summary, to precede a full discussion. The full discussion, however, did not appear until some two years later, on June 27, 1885,[23] which was some time after the discovery of the Edison effect had been announced. In this latter paper he notes that in some cases where only carbon deposit existed he observed the same molecular shadow as in the case of the copper deposit, wherever both legs of the filament were in the same plane, and the filament had burned out due to the development of a hot spot.

Meantime, Sir William Preece had returned from America with the fruits of his "persuasive eloquence" in the form of some of Edison's lamps. With these lamps he proceeded to duplicate the experiments he had observed in America and make quantitative

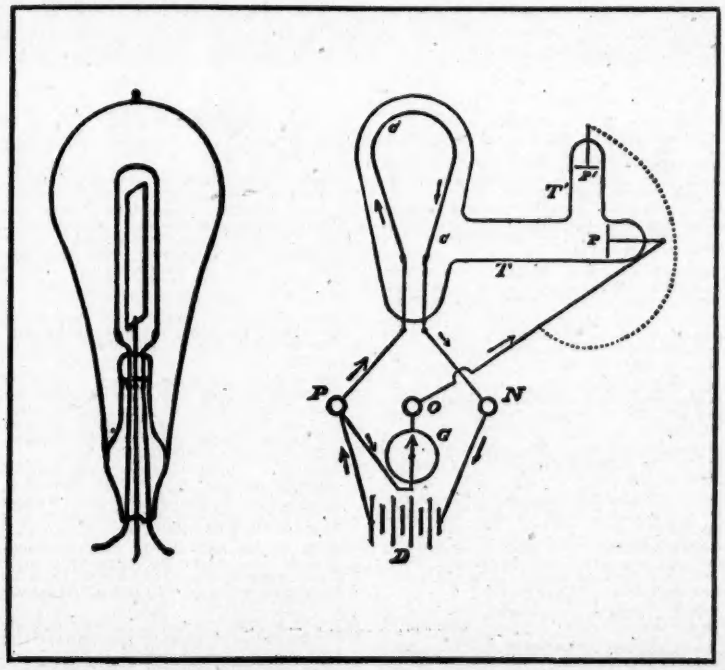

Fig. 1. Drawing of Edison effect lamp. Reproduced from U.S. Pat. No. 307031, issued October 21, 1884.

Fig. 2. Edison effect lamp used by Prof. Houston. Reproduced from "Trans. A.I.E.E." 1884.

measurements of the Edison effect. The results of these experiments were presented to the Royal Society in 1885.[26]

The paper opens by describing the experiments he had witnessed in America and then goes on to describe his own work using Edison's lamps. It is in this paper that we first find mention of "blue glow" or "blue effect" (due to the ionization of the residual air) which defied explanation for a long time. This appeared when the lamps were operated somewhat above their rated voltage. In the presence of this blue glow, Preece observed that current could be made to flow not only from cold to hot electrode, but also in the reverse direction.

He observed that the current was unaffected by the material of which the cold electrode was composed, but increased rapidly with increasing potential across the lamp. That is, he confirmed Edison's observation that this effect was proportional to the degree of incandescence of the lamp, as stated in his patent which had previously been issued.

On February 14, 1890, Fleming gave a Friday discourse before the Royal Institution on "Problems in the Physics of an Electric Lamp."[25] He again discussed molecular shadows and the reason for their formation. He also reviewed the work of Preece and repeated his experiments. In addition he showed that a single Clark cell would cause a flow of current across the vacuous space if the positive pole of the cell was connected to the cold electrode, but that if the battery was reversed there was no flow of current. This was in agreement with the results attained by Hittorf in 1884, who showed that even a small voltage was sufficient to send a current across the vacuous space, provided the cathode was a high temperature and the positive pole of the battery was connected to the cold electrode (plate).

Fleming also showed that if the cold electrode is heated to incandescence then the current may be made to flow, by the use of the external battery, in either direction through the vacuous space. Fleming did this by means of the apparatus shown in Fig. 6. It should be remembered that this same conclusion was reached by Becquerel, with somewhat poorer vacua, in 1853.

These investigations were carried still further and resulted in another paper before the Physical Society of London on March 27, 1896, and entitled "A Further Examination of the Edison-Effect in Glow Lamps."[26] In this paper Fleming repeated some of the quantitative experimental work previously done by Preece and gave a curve which showed the relation between the potential across the lamps, and the current through the vacuous space. He also announced that even if alternating current was used to heat the filament, that a unidirectional current was obtained in the cold electrode circuit.

The last important work prior to the application of the vacuum tube as a rectifier of high frequency oscillations in wireless telegraphy is recorded in a paper given before the A.I.E.E. in February, 1897, by John W. Howell.[27] This paper was intended as a discussion of the paper by Houston, previously mentioned. It discusses the Edison-effect phenomena which occur in lamps when the "blue glow" is pronounced, and states that the presence of the blue glow indicates the passage of electric current across the vacuous space. This paper is remarkable in that it is the first to show that currents of more than a few milliamperes may be made to flow across the space at moderate voltages. Howell states that he had measured vacuous currents in an ordinary carbon incandescent lamp, of more than 25 amperes,, which were sufficient to expand the platinum lead-in wires and shatter the glass.

Up to this time, it is to be noted, no one except Edison had shown any technical application of the Edison-effect. It is probable that Edison did so primarily for the purpose of obtaining patent protection, although Frank J. Sprague, in a letter to William J. Hammer, dated December 27, 1883,[28] praises the arrangement as an extremely sensitive indicator of small changes in voltage at the operating potential of the lamps.

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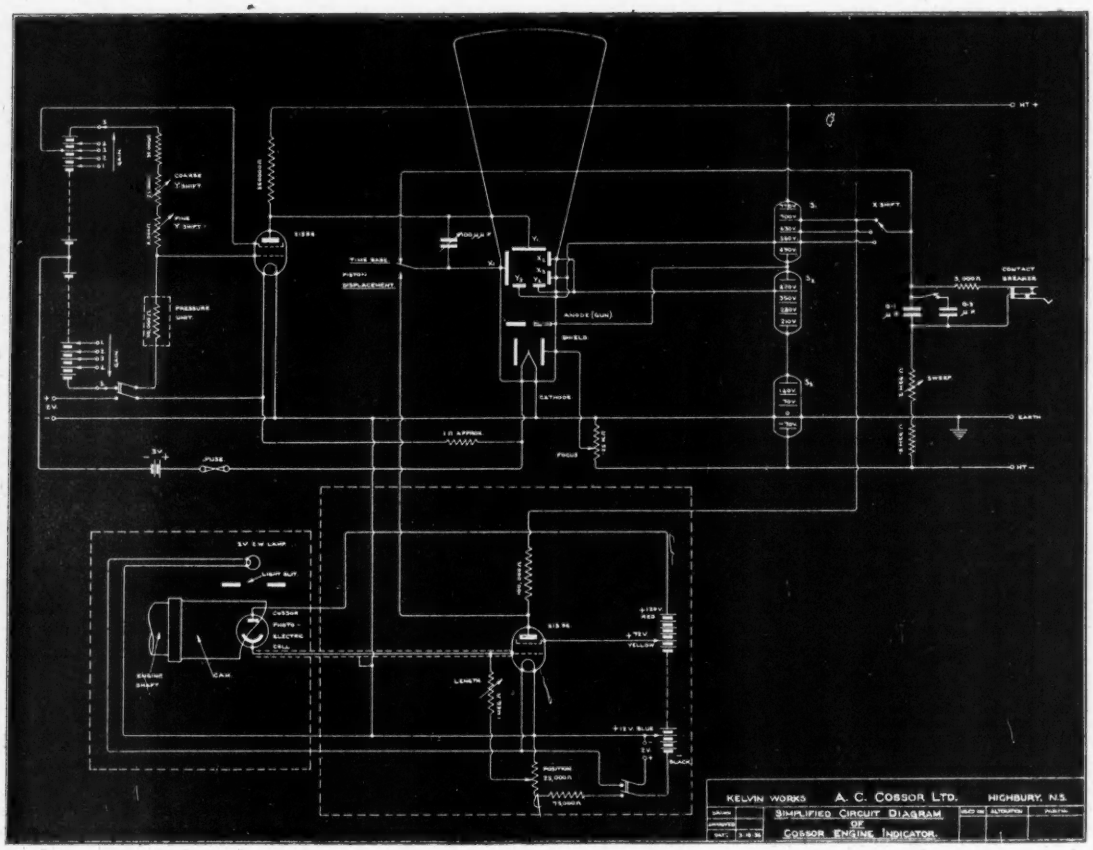

The C.-R. Tube in Mechanical Testing

By E. CATTANES, M.Brit.I.R.E. *

A critical review of the application of the Cathode-Ray Tube to mechanical measurements and the pick-up devices available for use with it.

The Cathode-Ray Tube

IT is assumed that the construction and principle of operation of the cathode-ray tube are well known. The high vacuum tube with electrostatic focusing and deflection is implied, as this is now the accepted standard for measurement work. Its chief advantages from the operational standpoint, and therefore necessarily including consequential advantages, are the following :—

(1) For practical purposes it is an inertialess indicating device.

(2 It possess a two-dimensional recording field.

(3) It provides visual indication and with it the facility for the examination of the law of recurrent phenomena irrespective of the repetition frequency.

(4) It enables direct photographic recording.

(5) It possesses high comparative accuracy.

(6) It is not subject to wear, as are other devices possessing moving parts.

(7) It is reliable and robust and not damaged by sustained overloads.

Its disadvantages are, however, not generally recognised. They are :—

(1) The cathode-ray tube is an inherently insensitive device.

(2) Its direct use on accurate quantitative work is difficult.

(3) Its successful application to mechanical test work is entirely dependent on the performance and characteristics of the converter units, usually called pick-up devices, which must be used to convert the mechanical effect investigated into the voltage change required for application to the cathode-ray tube or its related amplifiers.

The elimination of the second difficulty involved the progressive development of the cathode-ray tube as a measuring instrument, as is essential for its use in industry.

With regard to the last point, notwithstanding that the tube as now produced is completely satisfactory in other respects, its application to mechanical tests is essentially dependent on the type of pick-up device used. It is for these reasons, there-

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fore, that we are induced to examine both the cathode-ray tube and the pick-up devices themselves.

The Cathode-Ray Oscillograph

In the early cathode-ray tube the spot deflection was not proportional to the voltage applied to the deflector plate, and the use of such a tube on quantitative work entailed calibration of the whole screen area. In time the various distortions responsible for this condition were individually recognised, and without discussing them in detail it can be stated that they were progressively eliminated, and that to-day most of them have been or can be corrected, either in the tube or in the design of the attendant equipment, to an extent sufficient to keep the resulting error below the acceptable limit.

The tube sensitivity is a function of the anode potential and the calibration is affected by its variation. Therefore to meet the requirements of quantitative work some system of stabilisation of the power supply is desirable. It is somewhat difficult when using the electronic method because of the high voltage involved. It can, however, be done if required.

The low sensitivity of the cathode-ray tube makes the use of an amplifier essential, as voltages (of the order of 250 to 1,000) required to scan the screens of the usual tubes are not directly available from pick-up devices or attendant pre-amplifiers. The frequency range required to cover all mechanical effects is from 0 to 100,000 c/s. A symmetrical D.C. driver amplifier providing this performance is thus required, which for calibration purposes must also be stabilised electronically. This amplifier should be visualised as forming part of the tube, not only because by its means certain tube distortions (such as trapezium) can be eliminated, but because the combination comprises a unit which virtually replaces a meter or the usual indicating instrument.

This basic unit is only suitable for use with a moving film camera, as obtains when permanent records are required. Nevertheless, to make full use of the cathode-ray tube a time base should be included. A stationary trace of repeating wave forms can thus be obtained. The recurrency of the traverse can be automatic or controlled electrically or mechanically to synchronise with the frequency of the effect examined. The time base should also be capable both of expanding a small detail of the trace and also providing single stroke operation for the photography of transients. Hard valve time bases fully meeting these requirements are

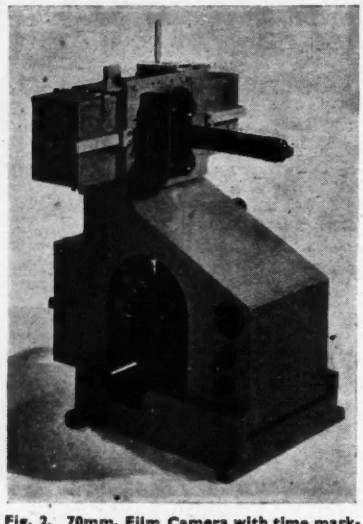


Fig. 2. 70mm. Film Camera with time marking facilities.

available, and when included in the tube unit described above form what may be considered as the basic oscillograph for industrial work.

So far, we have assumed a single record, but in practice it is often necessary to examine more than one related effect. The Double-Beam Tube meets this requirement without the need of further elaboration of the oscillograph unit described above. The time base is common and the two valves of the symmetrical amplifier can be adapted for independent, single stage, asymmetrical operation. The only duplication is in the input circuit arrangements. Fig. 1 illustrates a record of torsional oscillation of an engine shaft with cycle and absolute time marking pulses obtained on a double-beam tube.

Unfortunately, in an increasing number of industrial tests, even two records are often not sufficient. It is not convenient to adopt more than two beams per tube unless additional electron guns are used, and as this is tantamount to duplication of the tube, this latter expedient is preferable. By using two double-beam tubes four simultaneous records can be obtained. Furthermore, that part of the film corresponding to the interspace between the tubes can also be used for time marking, making a total of five photographic traces on a single 70 mm. film. Fig. 2 shows a separate film camera, illustrating the mounting of the double lens and time marking system, and finally, Fig. 3 illustrates a representative record. Units of this type can be made sufficiently robust for use for tank or traction recording work, or other field tests. When necessary the indicating and recording equipment can be located at any distance required for the pick-up device and thus away from the site of test.

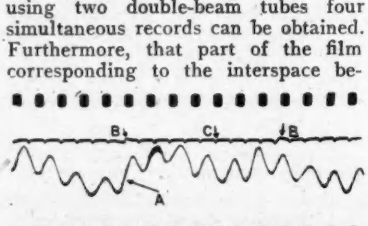


Fig. 1. 35mm. moving film record with Double Beam Cathode-Ray Tube.
(A) Torsional oscillation on an engine shaft.
(B) Cyclic time marking.
(C) Absolute time marking.

The technique covering the electronic circuits between the pick-ups and the cathode-ray tube indicator is now well established. At least it is theoretically possible, though in practice often difficult or expensive, to produce apparatus which is fully satisfactory in this respect. The elaboration or expense will be dependent on the class of work, the method used, the type of pick-up chosen, and, above all, the accuracy required in the quantitative determinations. Nevertheless, the basic cathode-ray oscillograph equipments described so far as suitable for use in almost every class of industrial test work and with any of the pick-up devices now to be examined.

Pick-up Devices

Mechanical tests in which the cathode-ray tube can be used may conveniently be sub-divided into two classes:—

Dynamic Tests.

Covering the functional test of mechanical apparatus and comprising the determination of one or more of the following fundamental effects: pressure, movement, velocity and acceleration.

Static Tests.

Concerned with the examination of materials, such as the detection of flaws within the material itself or the delineation of its contour or surface condition.

Most of the pick-up devices to be described can be applied to both classes. The functional tests are obviously the most important. Generally speaking, an apparatus designed to indicate one of the basic effects mentioned can be applied to all the others. Theoretically, this can be done electronically within the instrument by differentiating or integrating circuits, and mechanically by adapting the design of the pick-ups themselves. In practice, however, such conversions are not always possible or satisfactory.

Devices for converting mechanical

effects into electrical energy—the so-called "pick-ups"—are necessarily restricted in number.

Those making use of piezo-electric phenomena or magneto-striction are self-excited and are reversible in action in that they produce a voltage under mechanical stress and a mechanical movement under a voltage stress.

Other pick-up devices, such as condensers, photo-electric cells, and resistance elements, require to be polarised either by direct or alternating current, or by H.F. current.

The function of the associated apparatus is then to provide the polarising voltage or current, the bridge input circuit, the amplifier, converter, or detector before the converted energy is applied to the oscillograph.

According to the characteristics of the pick-up and method of use, the records obtained may be proportional either to the effect investigated or to its derivative. The former only is capable of static calibration.

The various devices possess advantages and limitations, and as is to be expected, their relative value also depends both on the method of use and on the type of application. In design they all involve both mechanical and electrical considerations, and this is a basic difficulty which is absent in the cathode-ray tube section of the apparatus.

All completed pick-ups are to a greater or lesser extent temperature-sensitive. Some are inherently so, and when used in applications involving large changes of temperature the design must include provision for temperature compensation. It is usual to provide liquid cooling, more so in the case when large changes of pressure are also involved, as in Engine Indicator work, to avoid the diaphragm becoming plastic. In this latter case a supported diaphragm is usually indicated.

We can now examine the chief devices individually from a technical aspect. It will not be possible in this brief survey to discuss design details or indicate the manner in which each is used in the various applications mentioned.

Capacitances

Pressures or movements can be made to change the capacitances of the condenser of suitable design having moveable diaphragm or plate. In all cases a gaseous, liquid or solid dielectric can be used. Irrespective of the method of use the condenser element possesses certain inherent advantages, which are :—

(1) It is suitable for use at the highest frequencies and therefore indicated for impulse tests, shocks, explosions, etc.

(2) It is equally effective for tension or compression.

(3) It is free from hysteresis when used with a suitable (air) dielectric.

(4) It is not inherently temperature sensitive.

(5) The dielectric can be used as a cooling agent.

(6) It is the easiest to apply on most applications and is suitable for the direct investigation of pressures, movements, velocities and accelerations.

(7) It is the most adaptable and in many movement tests it can be applied permanently to the machine without interfering with its operation.

(8) With a solid dielectric and supported diaphragm it is almost indestructible and suitable for the highest pressures.

(9) Is suitable for use on surface or profile analysis tests.

(10) Is suitable as detector of ultrasonic vibrations on crack detection tests.

It is generally accepted as being the most versatile pick-up device and is used also for detonation detection, torsional oscillations, vibrations, and other movements. A design suitable for use on Engine Indicator tests is shown in Fig. 7.

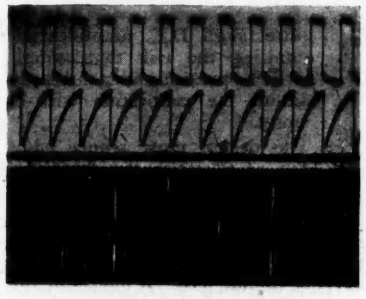


Fig. 3. A representative 70mm. film multiple record obtained with the instrument of Fig. 2. comprising four records plus central time marking.

D.C. Polarisation

According as to whether the time constant of the pre-amplifier input circuit is large or small the voltage change obtainable is proportional to the applied pressure (or movement), or to its rate of change. This method simplifies the construction of the apparatus, but has the following disadvantages :—

(1) Static calibration is impossible.

(2) The pick-up possesses a high impedance and is thus subject to electrical interference.

(3) It requires a high insulation resistance and the attendant risk of leakage effect entails care in use. This applies also to the input circuit of the instrument.

(4) The device can only be used at a limited distance from the rest of the apparatus.

H.F. Polarisation

The pick-up device can be made to modulate the H.F. polarisation either in frequency or amplitude. Used with the bridge input network the change of impedance resulting from the movement of the diaphragm is proportional to the applied pressure or movement. The further advantages gained are as follows :—

(1) It will respond to the D.C. component of the effect.

(2) It can be calibrated statically, and is suitable for hydrostatic pressures.

(3) A low impedance pick-up can be made and without the use of a transformer will match a low impedance line which is less liable to electrical interference.

(4) All the apparatus can be kept at whatever distance is required from the pick-up device and machine on test. Thus the risk of vibration effects is reduced to a minimum.

The only disadvantages are :—

(1) The complication of electrical circuits.

(2) The high cost of the equipment.

Resistances

There are certain substances which change their internal resistance under pressure, and they all possess the following features in common :—

Advantages.

(1) They respond to the D.C. component and are suitable for hydrostatic pressures.

(2) Static calibration is possible.

(3) They possess low impedance, which is almost independent of frequency.

(4) When insulated, are suitable as immersion units.

Disadvantages.

(1) These elements are invariably temperature sensitive.

(2) They are not suitable for measuring movements.

(3) They are more suitable for compression pressures.

(4) Liquid cooling of pick-up device is essential.

There are two distinct types of resistance element :—

(1) Carbon Composition

This assumes a mixture containing carbon to form a solid compound, and excludes the carbon pile and granules type of element. The latter is now obsolete as the effect utilised was the change of contact resistance which is inherently unstable.

Advantages.

(1) High sensitivity.

(3) Maximum simplicity of the apparatus.

Disadvantages.

(1) Fragility of the element, which is not suitable for pressures above 1,000 lb./sq. in.

(2) The low pressure range is restricted by interference effects within the element.

Nevertheless, it is possible to produce the simplest of all pressure recording equipments with this type of Pressure Unit, as shown in the circuit diagram on p. 277. This equipment is capable of producing results which are comparable to the best obtained with more complicated apparatus. A representative Engine Indicator diagram on a piston displacement and crank angle base is also shown in Figs. 5 and 6 respectively.

(2) Metal Alloys

Certain alloys, such as manganin in particular, are pressure sensitive, but unfortunately the change of pressure is of the same order as the change of temperature and is very small. Elements of this type are still in the experimental stage. There are other alloys which exhibit the same properties and though promising are still in the experimental stage. These are certain silver alloys, silver-manganese, and silver-manganese-tin alloys, as also dilute binary alloys of copper silver and gold. The silver manganese alloys appear so far to be the most satisfactory in possessing a high pressure coefficient of resistance.

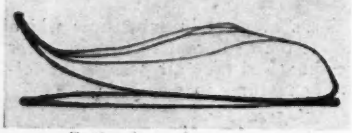


Fig. 5. Engine Indicator diagram on a Piston Displacement Device obtained on Cathode-Ray Indicator (p. 277)

Advantages.

(1) The element is stable and free from internal interference.

(2) It will withstand very high pressures.

Disadvantages.

(1) It entails complicated pick-up design for compensation of temperature effect.

(2) It has low sensitivity and requires high D.C. amplification, entailing the risk that, should drift be present under these conditions the calibration will be upset.

(3) The design must reduce eddy-current effects in the element.

Electromagnetic Devices

Movements or pressures can be made to move the diaphragm or armature of a suitable electromagnet, thus varying the air gap. A device of this sort possesses the following common features:—

Advantages.

(1) It is suitable for both tension and compression.

(2) It is simple to design.

(3) It possesses low impedance.

Disadvantages.

(1) It is restricted in frequency range.

(2) It is subject to phase and frequency distortion.

According to the method of operation these features are modified as follows:—

D.C. Polarisation

When polarised by D.C., or when a permanent magnet is used, the displacement of the diaphragm induces a voltage in the coil which is proportional to the rate of change of the effect applied. This is a fundamental drawback of the device, as electrical integration is required to obtain the record of the pressure or movement effect.

H.F. Polarisation

The change of impedance due to the movement of the armature creates an out-of-balance H.F. voltage on the bridge circuit input which is proportional to the pressure or movement applied. This makes the device suitable for static calibration, provided the H.F. voltage is not rectified. This is not a satisfactory method as the record required is an envelope of a waveform and its outline is often unstitable for photographic recording.

Photo Cells

The Photo Cell must be used in conjunction with cams and diaphragms and is more suitable for investigating movements than pressures Nevertheless, it has been applied successfully to the latter by using the light reflected by diaphragm movements with changes in pressure. The law of variation is complicated, but it can be made sensibly linear over the operating range by suitable design of the diaphragm itself and the optical system. This entails the use of charts and an assortment of diaphragms. The device can be made to avoid temperature effects, but it is more subject to the effects of vibration. To overcome these and other difficulties, such as the variation in photo cell cathode sensitivity, the device should be used on the "variable intensity" rather than on the "variable area" principle, although the latter is more efficient and simple to carry out. An illustration of its use as a piston displacement device is given on the circuit diagram of the Engine Indicator shown at the head of this article.

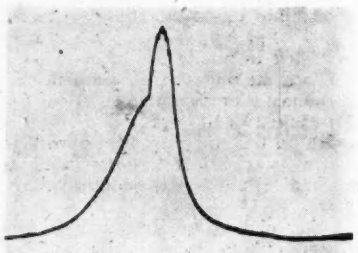


Fig. 6. Engine Indicator diagram on a crank angle base obtained on Cathode-Ray Indicator (p. 277)

Piezo-Electric Crystals

Use is made of the well-known phenomenon that certain crystals will develop an electric charge across a pair of faces when pressure is applied. Quartz, tourmaline and Rochelle are the more common crystals in use. They are less adaptable for investigation of movements, but are suitable for certain static tests. They are generally too fragile for many mechanical applications. The various crystals have somewhat different characteristics, and quartz is the most favoured.

Its advantages are:—

(1) It is mechanically the strongest crystal.

(2) It has no hysteresis.

(3) Its response is directly proportional to pressure.

(4) It has good electrical insulation.

(5) It can be calibrated statically.

Its disadvantages are:—

(1) It has low sensitivity.

(2) It has high impedance, and is thus subject to electrical interference, vibration effect and loss of insulation.

(3) It is not suitable for hydrostatic pressures. In this case tourmaline should be used and can be applied as an immersion unit.

In addition to pressures, quartz is

(*Continued on p.* 295.)

Dust Cored Coils

Conclusion: Part V.—Methods of Measurement

By V. G. WELSBY, B.Sc. (Eng.)*

Introduction

IN the previous parts of this article, it has been assumed that it is always possible to measure the effective inductance and resistance of a coil experimentally. In this final part, it is proposed first of all to deal briefly with some available methods of measurement and then to proceed to a consideration of the practical difficulties involved and the accuracy obtainable. Finally, a more detailed description will be given of a particular piece of apparatus used by the author for the experimental analysis of coil losses.

Impedance Measurement

A.C. Bridges

The possible variations of the Wheatstone bridge circuit are almost unlimited, and only a brief summary can be given here. Further details can be obtained from standard textbooks or from references given in the bibliography.[1, 2]. A.C. bridges for coil measurements can be classified broadly into two types; resonant and non-resonant. In the former type, as the name suggests, the test coil is connected either in series or in parallel with a standard variable condenser which is adjusted to resonate at the testing frequency. The non-resonant type may use either a condenser or an inductor as a reactance standard. Fig. 5.1 shows the fundamental bridge circuit, and Fig. 5.2 shows some typical arrangements of the bridge arms. In each case, the conditions for balance are indicated. L_k, C_k and R_k represent standard inductors, condensers and resistors, respectively, whilst Z is the unknown impedance of the test coil.

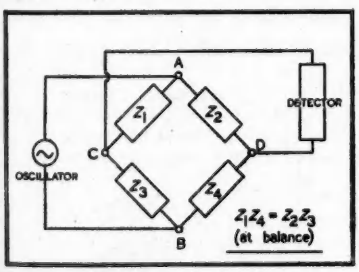


Fig. 5.1. Fundamental A.C. bridge circuit.

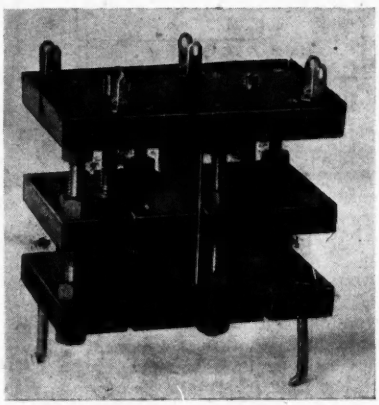
The Q-Meter [3, 5]

The operation of this instrument depends on the fact that if a known e.m.f. at the resonant frequency is applied across a coil and condenser in series, the ratio of the potential difference between the coil terminals to the applied e.m.f. is equal to Q, the "magnification" or "quality factor" of the coil (neglecting condenser losses). The circuit arrangement in its simplest form is shown in Fig. 5.3. An oscillator feeds a constant current; indicated by a meter M_1; through a resistance R_2 which is chosen so that it is small compared with the effective resistance of the test coil. The voltage V_1 across R_2 is then practically unaffected by the tuned circuit and, since $Q = \frac{V_2}{V_1}$, the high-impedance valve voltmeter M_2 can be calibrated directly in terms of Q. The inductance and resistance of the coil can then be obtained from the relations:—

$$L' = \frac{1}{\omega^2 C_k} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$R' = \frac{\omega L'}{Q} = \frac{1}{Q\omega C_k} \quad \ldots\ldots (2)$$

Although its accuracy is limited by condenser losses, particularly when using an additional external condenser for measuring coils of small inductance, the Q-meter has the great advantage that it is simple to operate and is direct-reading. This makes it very useful for routine comparison measurements on batches of coils wound to the same specification. It has also been found useful for the measurement of self capacitance, an operation which is somewhat tedious by other methods. A description of the methods used may be of interest.



Mounting for two adjustable pot type coils with screening can removed. (G.P.O.).

Measurement by Self Capacitance by Q-meter

At its natural resonant frequency, a coil behaves as a pure resistance. If, therefore, another coil of smaller inductance is tuned on the Q-meter to the natural resonant frequency of the original coil, the addition of the latter in parallel will merely cause a reduction of apparent Q and will not require a change in the setting of C_k. If the frequency is not correct, and C_k has to be decreased to retune, this means that the test coil behaving as a *negative* reactance, and is thus working above its own resonant frequency. On the other hand, if C_k has to be increased, the testing frequency is too low.

A few trials should suffice to enable the natural resonant frequency of the test coil to be determined quite accurately. In general, the effective permeability of a dust-cored coil can be taken as constant at least up to its natural resonant frequency, so that the self capacitance can be obtained quite easily from the inductance value measured at low frequencies. An exception to this rule might arise if a high permeability toroidal core, intended for use at low frequencies, were wound with a small number of turns so that both the inductance and self capacitance were low. In such a case the self capacitance can be estimated by measuring the change of apparent inductance with frequency at low frequencies, or by measuring the apparent capacitance of the coil at frequencies well above resonance. This represents a more complicated problem, however, which

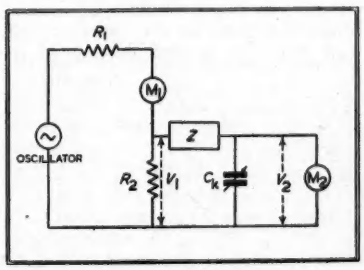


Fig. 5.3. Q-meter circuit.

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is outside the scope of the present article.

Reactance and Resistance Variation

Here, as with A.C. bridge circuits, there are many possible arrangements, of which only a brief summary can be given. All these methods depend on the "damping" effect of coil losses on the resonance curve of a tuned circuit including the test coil and a standard condenser. For example, suppose a constant e.m.f. E is applied to the coil and condenser in series (*see* Fig. 5.4) and the condenser value C_k is adjusted to give the maxi-current I. If now the reactance of the tuned circuit is changed, either by altering the setting of C_k or by altering the frequency, until the current has dropped to $I/\sqrt{2}$, it can be shown that the Q of the coil (neglecting condenser losses) is given by the relations shown in Fig. 5.4 (a). In practice, the two points, one on either side of the resonance peak, would be found at which the current had dropped to the required value, and the mean value of Q taken. As an alternative method, a resistance R_k can be introduced into the circuit and adjusted until the peak current with it is exactly half that without it.

Then, clearly, the loss resistance of the coil must be equal to R_k (*see* Fig. 5.4 (b)). It is possible to devise corresponding circuits, using parallel instead of series resonance. The accuracy obtainable by all the above methods is comparable with that obtained with the A.C. bridge, the main disadvantage being that the accuracy depends on the calibration of a meter. Further difficulties are caused by the fact that the current flowing in the coil is not constant throughout a measurement.

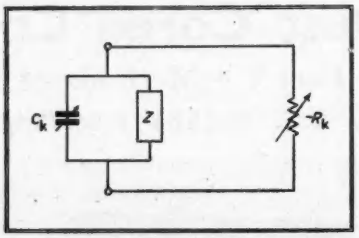


Fig. 5.5. Resistance neutralisation circuit.

Resistance Neutralisation

If a resonant circuit could be constructed using pure loss-free reactance elements, a small electrical impulse would start an oscillation which would persist indefinitely. The same effect can be produced in a practical resonant circuit if it is possible to introduce another component behaving as a negative resistance of such a value that it exactly neutralises the total loss resistance of the circuit. Any device which draws a *decreasing* current as the supply voltage is increased has a negative resistance, and several electronic circuits are known which have negative resistances over a limited range of applied voltage. For the present purpose, the negative resistance has to be adjustable, stable and capable of accurate calculation from the known circuit constants. Although the "dynatron" circuit has been used[4], it is probable that a more satisfactory method would be to use a stabilised feedback circuit whose negative resistance can be made practically independent of supply voltage fluctuations.[7] A parallel resonant circuit is most suitable for resistance neutralisation measurements, and the "negative resistance" is connected in parallel (Fig. 5.5). If now the value of the latter is steadily decreased from a high value, a point will be found at which oscillation will just take place (as indicated by some form of detector very loosely coupled to the test circuit). The loss resistance of the coil (neglecting condenser losses) is then given by

$$R' = \frac{1}{\omega^2 C_k^2 R_k}$$

and the inductance can be calculated from the tuning condenser setting necessary for oscillation at the test frequency.

Other Methods

There are undoubtedly other possible methods of measurement which are not included in the more usual ones mentioned above. There is, for example, the calorimetric method in which the power losses are measured directly by the amount of heat produced, but a consideration of the small magnitude of the quantities involved in the case of a dust-cored coil will show how difficult this method would be to apply. A method has also been described[6] in which the power factor or "loss angle" of a coil is obtained directly by means of a cathode-ray oscillograph, but this is not likely to be very accurate for low-loss dust-core coils.

Sources of Error

It has been shown that all the practical methods of measurement involve the use of a standard reactance which may consist either of an inductor or a condenser. Losses in the standard reactance cannot be directly distinguished from those in the test coil,

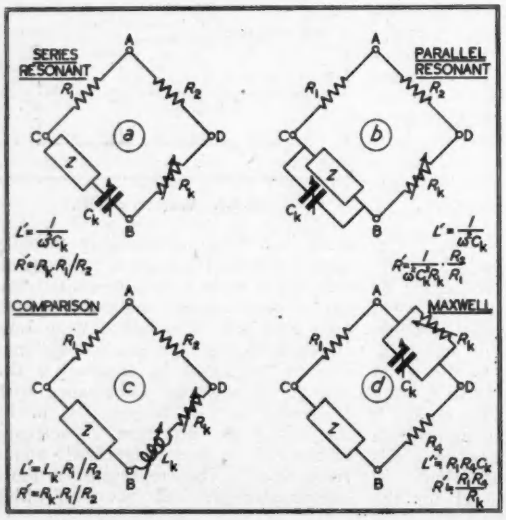


Fig. 5.2. (left) Balance conditions for typical A.C. bridge circuits.

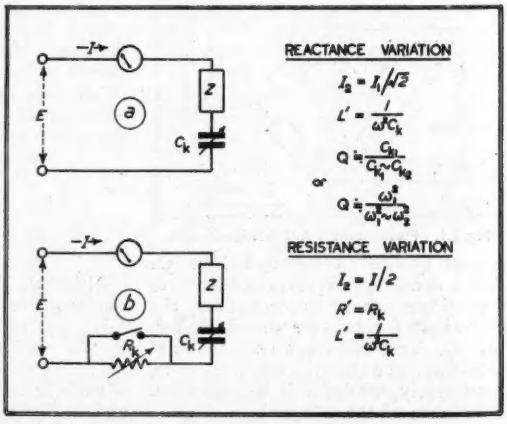


Fig. 5.4. Reactance variation and Resistance variation circuits.

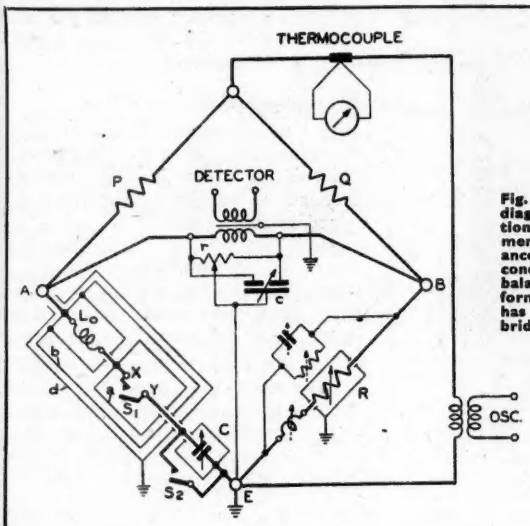


Fig. 5.7. "Complete circuit diagram of partial substitution bridge, showing arrangement of screens. The resistance r and differential condenser C are used to balance the output transformer so that the detector has no influence on the bridge balance."
(By courtesy P.O.E.E.J.)

and they thus introduce errors into the measured resistance. In the same way, where a standard resistance is used, any stray reactance associated with it will cause errors in the measured inductance of the test coil. In addition, of course, further errors may be caused by losses in the connecting leads, and stray couplings between them, although such errors can be minimised by making an initial adjustment without the test coil and then noting the incremental change of reactance and resistance when the coil is added (sometimes called the "Partial Substitution" method). Let us assume that the Q of the standard reactance and resistance are Q_x and Q_r respectively, and are both constant over the range of adjustment involved. Then, if the *apparent* impedance of the test coil, as indicated by the settings of the standard components is $R_1 + j\omega L_1$.

Then $R_1 + j\omega L_1 =$

$$R' + j\omega L' \pm jQ_rR_1 + \frac{1}{Q_x}\omega L_1 \ldots (3)$$

or, since $R' \doteqdot R_1$ and $L' \doteqdot L_1$

$$R_1 + j\omega L_1 \doteqdot (R' + \frac{1}{Q_x}\omega L') + j(\omega L' \pm Q_rR') \quad \ldots\ldots (4)$$

or $R_1 + j\omega L_1 \doteqdot$

$$R'(1 + \frac{Q}{Q_x}) + j\omega L'(1 \pm \frac{1}{QQ_r}) \quad (5)$$

Equation (5) indicates the conditions for a given percentage error in either resistance or inductance measurements. Suppose, for example, that both errors are not to exceed $\pm 1\%$.

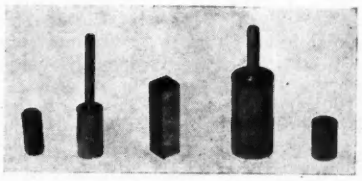
Then $Q_x < 100\ Q$

And $Q_r > 100\frac{1}{Q}$

This means that, if Q is 300, the reactance standard must have a Q of at least 30,000 and the resistance standard must have a Q of not more than $\frac{1}{3}$. From this it can be seen that it is the error in the measured resistance which is going to cause the most trouble, since it is obviously more difficult to construct a standard inductor or condenser with a Q of 30,000 than it is to construct a standard resistance with a Q of $\frac{1}{3}$!

Accuracy Required

At first sight it would appear that the above requirements rule out the use of an inductor as a standard. This is not necessarily true, however, since the Q of the reactance standard can be allowed to be considerably smaller, provided its value is known sufficiently accurately. In the case quoted above, for example, it would be sufficient if the value of Q_x were only 300, provided it were known to within $\pm 1\%$. This condition could be satisfied by an air-cored coil whose apparent resistance at the testing frequency was only 1% above the D.C. resistance, and, as a result, this method is sometimes applied to the measurement of dust-cored coils at relatively low frequencies. It is possible to build standard variable air-dielectric condensers with a Q greater than 50,000, but their capacitance is limited to a few thousand $\mu\mu F$ by considerations of cost and size. For larger values of capacitance, mica condensers have to be used, having a Q of perhaps 3,000, so that coil measurements made with such condensers may have errors of the order of $\pm 10\%$ in the measured resistance. For many purposes this may be good enough, but much greater accuracy is needed in order to carry out a detailed analysis of the coil losses. The apparatus[8] described in the next paragraph enables a low-loss condenser to be used to measure a wide range of inductances and gives the value of R' to an accuracy of about $\pm 1\%$ ± 0.005 ohm at frequencies up to 500 kc/s.



Typical cores for pot type coils.

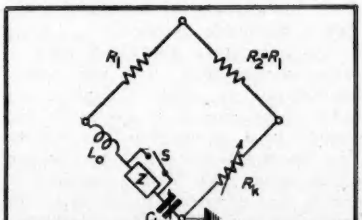


Fig. 5.6. Simplified circuit for partial-substitution series-resonant bridge with equal ratio arms.

Partial-Substitution Series Resonant Bridge

An equal ratio-arm, series-resonant bridge was chosen for the following reasons:—

(1) The fact that it is symmetrical with respect to the earthed point simplifies the screening problem.

(2) At balance, the "unknown" and "balance" arms are pure resistances which are small compared with the ratio arms. This minimises the effect of stray capacitances.

(3) The current in the test coil can be controlled and measured accurately.

Fig. 5.6 shows the fundamental circuit. The bridge is first balanced with switch S closed, and the condenser and resistance settings C_{k1} and R_{k1} noted. A new balance is then obtained with the switch open, thus bringing the test coil into circuit. If

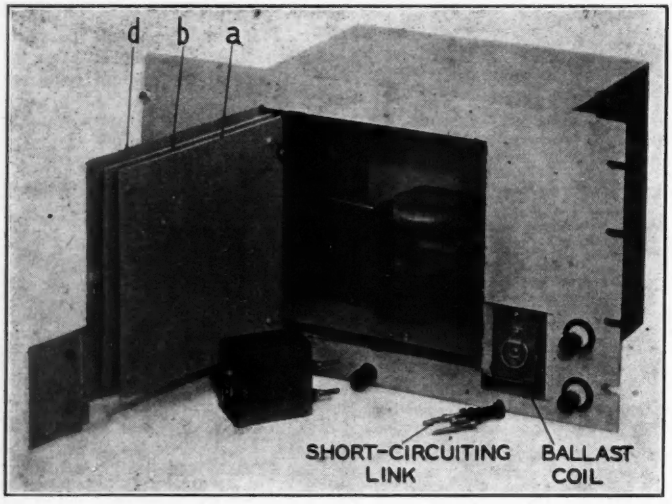


Fig. 5. 8. " Photograph of screening box showing plug-in ballast coils and a test coil in position for measuring."

(By courtesy P.O.E.E.J.)

the settings are now C_{k2} and R_{k2}, then

$$R' = (R_{k2} - R_{k1}) \quad \ldots\ldots\ldots (6)$$

$$L' = \frac{1}{\omega^2}\left(\frac{1}{C_{k2}} - \frac{1}{C_{k1}}\right) \quad \ldots\ldots\ldots (7)$$

Now, since C_{k2} must be smaller than C_{k1} it follows that the maximum condenser settings are fixed by the value of the "ballast coil" inductance L_o. The latter takes the form of a series of plug-in coils, one for each testing frequency, their inductances being chosen so that C_{k1} is always within the range of a low-loss tuning condenser. This method has the added advantage that errors due to connecting leads, etc., are cancelled out, and also that it is only the incremental change of condenser loss between the two settings which can affect the result. A complete circuit diagram of the bridge, including the screening arrangements, is shown in Fig. 5.7 The screening ensures that all stray capacitances are either neutralised or placed so that they can be allowed for. This point is dealt with more fully in an article in the *Post Office Electrical Engineers' Journal*.[8] Fig. 5.8 (reproduced from the article) shows the screen assembly with a toroidal test coil in position. In the original apparatus the test terminals consisted of brass cups containing mercury, and a small projection on the bottom of each cup dipped into a third mercury cup which pivoted on a lever, forming the switch S. This device has since been abandoned in favour of a simple plug and socket arrangement since trouble was experienced due to oxidisation of the mercury.

Oscillator and Detector

In conclusion, let us consider briefly the auxiliary apparatus required with any A.C. bridge. No hard and fast rules can be given about the design of a suitable oscillator, but it should be noted that for a bridge, such as that described above, in which the balance depends critically on the frequency, the oscillator must be extremely stable. This applies not only to the frequency stability over a period of minutes, but also to the complete absence of frequency modulation of the oscillator output by mains hum. The latter causes an interesting but troublesome effect. If the bridge is balanced at the mean frequency, then it follows that as the frequency varies some leakage must occur, and the magnitude of this leakage will vary over the cycle of the interfering hum. Thus, it will be impossible to find a true "null" point, and the accuracy of the bridge will be reduced. In other words, the balanced bridge converts the frequency modulation into an amplitude modulation. This trouble has been overcome by the use of a carefully designed feedback oscillator. As far as the detector is concerned there is little doubt that the well-known heterodyne principle, applied to convert the signal to an audio frequency beat, gives the best results. The frequency-changer should be preceded by a tuned H.F. amplifier to ensure that distortion produced by the iron-cored test coil itself is adequately suppressed. Aural methods, particularly using sensitive headphones, are to be preferred to visual ones, since the ear is capable of selecting the beat tone even in the presence of considerable interference.

Acknowledgment

The author wishes to acknowledge the permission of the Engineer-in-Chief of the G.P.O. Engineering Department to publish information contained in this article.

ERRATA

Part 1, para. 3, line 8, "μ_o" should read "μ".

Part 1, table I, heading of last column should read "μ_e" instead of "μ" and the last entry in this column should read "$\rightarrow 1$" instead of "1"

Part 2. The first sentence of para. headed "hysteresis loss" should be included in previous para.

Part 3, p. 192. Correction for self capacitance. In column 3 and in the curve of Fig. 3.2 f_o/f_r should read f_r/f_o. The vertical scale of Fig. 3.2 should read Q/Q'_{max} instead of Q_o/Q'_{max}.

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DATA SHEET 56

Aerial Characteristics—IV

Effect of Ground Losses on Field Strength

LAST month's Data Sheets dealt with the effects of ground losses on the directional characteristics of an aerial. In the case of grounded aerials whose length is short compared with the wavelength, ground losses will in addition have a very serious effect on the field strength obtainable for a given input power to the aerial.

The relative calculated field strengths of the polar diagrams accompanying Data Sheets 54 and 55, were based on the assumption that the current in the aerial was not affected by the losses in the ground. In practice, the presence of the ground will alter both the radiation resistance and the aerial and therefore for a given input power affect the magnitude of the aerial current.

Ground Currents

In the case of a grounded aerial displacement currents leave the aerial and, after travelling through space, finally flow into the ground where they become conduction currents. For the case of a homogeneous ground, "skin effect" (*see* Data Sheet No. 26) concentrates these earth currents into a layer near the surface of the earth, as they flow along radial lines back to the base of the aerial. If we start some distance from the aerial and proceed along an imaginary line towards the aerial, the conduction current flowing towards the base of the aerial is continually being added to by additional displacement currents flowing into the ground. The addition of these currents does not, however, necessarily increase the total current as all the individual components of the conduction currents have different phases.

The best way of illustrating the variation of ground currents with distance from the aerial is by imagining that a cylinder of thickness dx and radius x is sunk into the ground so as to be concentric with the aerial (*see* Fig. 1). The total earth current at a radius x is equal to the total current flowing radially inward across the surface of the cylinder. Let this current be I_x. G. H. Brown has shown that for perfectly conducting ground the absolute value of I_x is given by

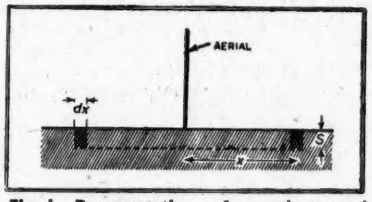


Fig. 1. Representation of zonal ground current by means of a cylinder of radius x.

$$|I_x| = \frac{I_o}{\sin G}\sqrt{1 + \cos^2 G - 2\cos G \cos\left[2\pi\left(\sqrt{\frac{l^2}{\lambda^2}+\frac{x^2}{\lambda^2}}-\frac{x}{\lambda}\right)\right]} \quad \ldots\ldots\ldots (32)$$

$$|I_x| \approx I_o \frac{1-\cos G}{\sin G} \text{ when } x \gg l \quad \ldots\ldots\ldots (33)$$

where as before I_o = current at the base of the aerial

l/λ = length of the aerial in wavelengths.

$$G = \frac{2\pi l}{\lambda}$$

For constant input power we replace I_o as before by

$$I_o = \sqrt{\frac{W_1}{R_B}}$$

Where W_1 is the input power to the aerial and R_B the Base Radiation Resistance.

Fig. 2 shows the manner in which the total ground current varies with distance from the base of the aerial for aerial heights of $o, \frac{\lambda}{16}, \frac{\lambda}{8}, \frac{\lambda}{4}, \frac{\lambda}{2}$ for a constant input power of 1 watt.

From these curves it will be seen that for aerials up to the order of a quarter of a wavelength long the ground currents are almost constant for distances greater than about a third of a wavelength from the aerial. This implies that for a constant radiated power, the power lost in the ground beyond a third of a wavelength is approximately constant as the aerial length is reduced from $\frac{\lambda}{4}$ to zero.

At shorter distances from the aerial the current in the ground rises rapidly as the aerial length is reduced and it is therefore particularly important to keep the conductivity of the ground high in this region, if excessive losses are to be avoided with short aerials.

Aerial Loss Resistance

If instead of a perfect ground we assume a ground whose conductivity is finite but sufficiently high to maintain as a first approximation the phase and magnitude of the earth currents at their original level, then it is possible to estimate the power lost in the ground. The phase and magnitude of the ground currents can only be assumed to be sensibly independent of the conductivity of the ground, if the conductivity is sufficiently high to ensure that the conduction ground currents are many times greater than the displacement currents in the ground (*see* Appendix).

Assuming (*see* Data Sheet No. 26) that the equivalent thickness S of the layer in which the ground currents travel (*see* Fig. 6) is given for a homogeneous ground by

$$S = \frac{10^9}{4\pi^2\mu\sigma f} \text{ cms.} \quad \ldots\ldots\ldots (34)$$

where f is the frequency in c/s. and σ is the conductivity in mhos/cm³. (the permeability μ is usually unity).

It can be shown that the power lost in a zone of the ground formed by a ring of thickness S and width dx (*see* Fig. 1) is given by

$$\frac{dW_x}{dx} = \frac{|I_x|^2}{2\pi x\sigma S} \text{ watts/metre} \quad \ldots\ldots\ldots (35)$$

if the distance x is measured in metres or (35) is in watts/cm. if x is measured in centimetres. We can also express this power loss in terms of a resistance referred to the base of the aerial.

$$\frac{dR_x}{dx} = \left|\frac{I_x}{I_o}\right|^2 \frac{1}{2\pi x\sigma S} \text{ ohms/metre} \quad \ldots (36)$$

when x is given in metres.

As $\frac{I_x}{I_o}$ is only a function of the ratio x/λ for a given value of l/λ (*see* equation 32) we can re-write this equation in the form

$$\frac{dR_x}{dx} = \left|\frac{I_x}{I_o}\right|^2 \left\{2\pi\left(\frac{x}{\lambda}\right)(\lambda\sigma S)\right\}^{-1} \text{ ohms/metre} \quad \ldots\ldots (37)$$

From equation (37) it will be seen that the term $(\lambda\sigma S)$ is proportional to $\lambda^{3/2}\sigma^{1/2}$ so that

$$\frac{dR_x}{dx} \propto \lambda^{-3/2}\sigma^{-1/2} \quad \ldots (38)$$

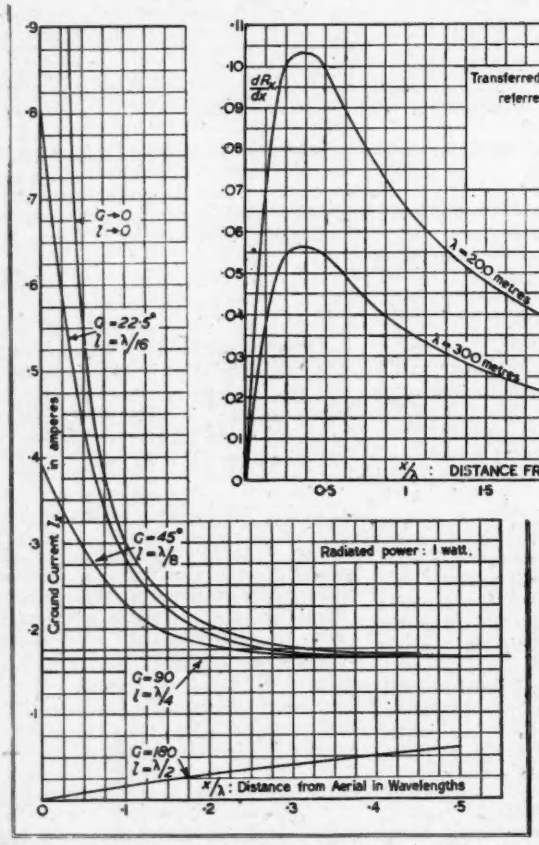
Ground Currents and Ground Losses

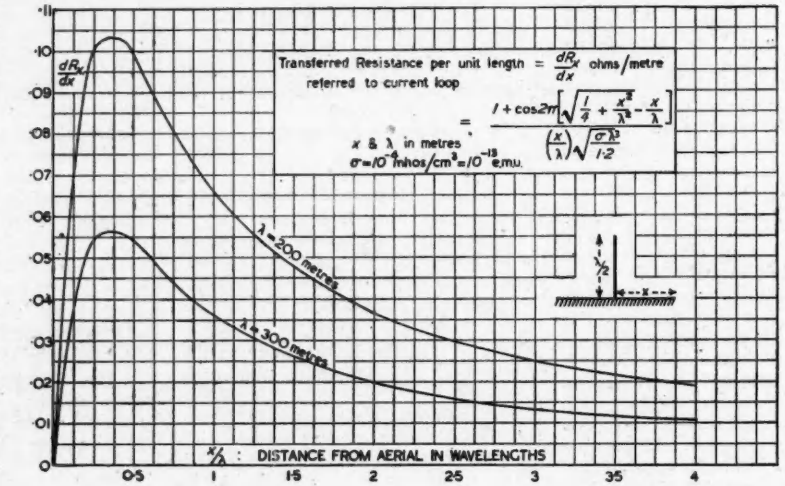
In the case of a ½-wave aerial dR_x/dx has to be transferred to the current loop instead of the base of the aerial by means of the relation $I_o = I_L \sin G$.

On Fig. 3 has been plotted the loss resistance of a grounded half-wave aerial with a ground of average conductivity, *i.e.*, $\sigma = 1 \times 10^{-13}$ e.m.u. or 1×10^{-4} mhos/cm³. Two curves are shown: one for a wavelength of 200 metres the other for 300 metres; the resistance scale for other conductivities and wavelengths can be easily changed by means of equation (38) provided the limiting assumption is borne in mind.

From the curves below it will be seen that in the case of a grounded half-wave aerial the zone of maximum transferred resistance per unit length occurs at approximately 0.35λ. With a quarter-wave aerial, however, the ratio $\frac{I_x}{I_o} = 1$ and is independent of x, therefore the maximum transferred resistance zone occurs near the base of the aerial and $\frac{dR_x}{dx}$ decreases inversely with an increase of the ratio $\left(\frac{x}{\lambda}\right)$.

The total loss resistance component of the aerial due to a finite ground conductivity is obtained by integrating the transferred resistance per unit length $\frac{dR_x}{dx}$ over all the zones.





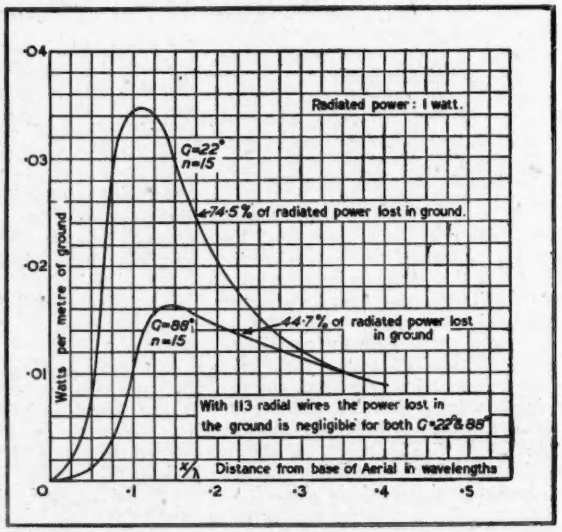

Radiated power: 1 watt.
G=22° n=15
74·5% of radiated power lost in ground.
G=88° n=15
44·7% of radiated power lost in ground
With 113 radial wires the power lost in the ground is negligible for both G=22° & 88°
Watts per metre of ground
x/λ Distance from base of Aerial in wavelengths

Fig. 2 (above). Calculated magnitude of total ground current I_x at a distance x from the base of grounded aerials of different heights, for a radiated power of 1 watt. (Perfect ground and sinusoidal current distribution assumed).

Fig. 3. Distribution of ground losses in neighbourhood of a half-wave grounded aerial, with a ground conductivity of $\sigma = 10^{-4}$ mhos/cm.^{3} = (10^{-13} e.m.u.).
(After G. H. Brown, Proc. I.R.E., Feb., 1935).

Fig. 4 (right). Power lost in ground with grounded ¼-wave aerial and ½-wave aerial with radial buried wire system 0.4 wavelengths long.
Ground conductivity $\sigma = 2 \times 10^{-5}$ mhos/c.m.^{3} $= 2 \times 10^{-14}$ e.m.u.
Number of radial wires = n
Wavelength 100 metres.
(After G. H. Brown, Proc., I.R.E., 1937)

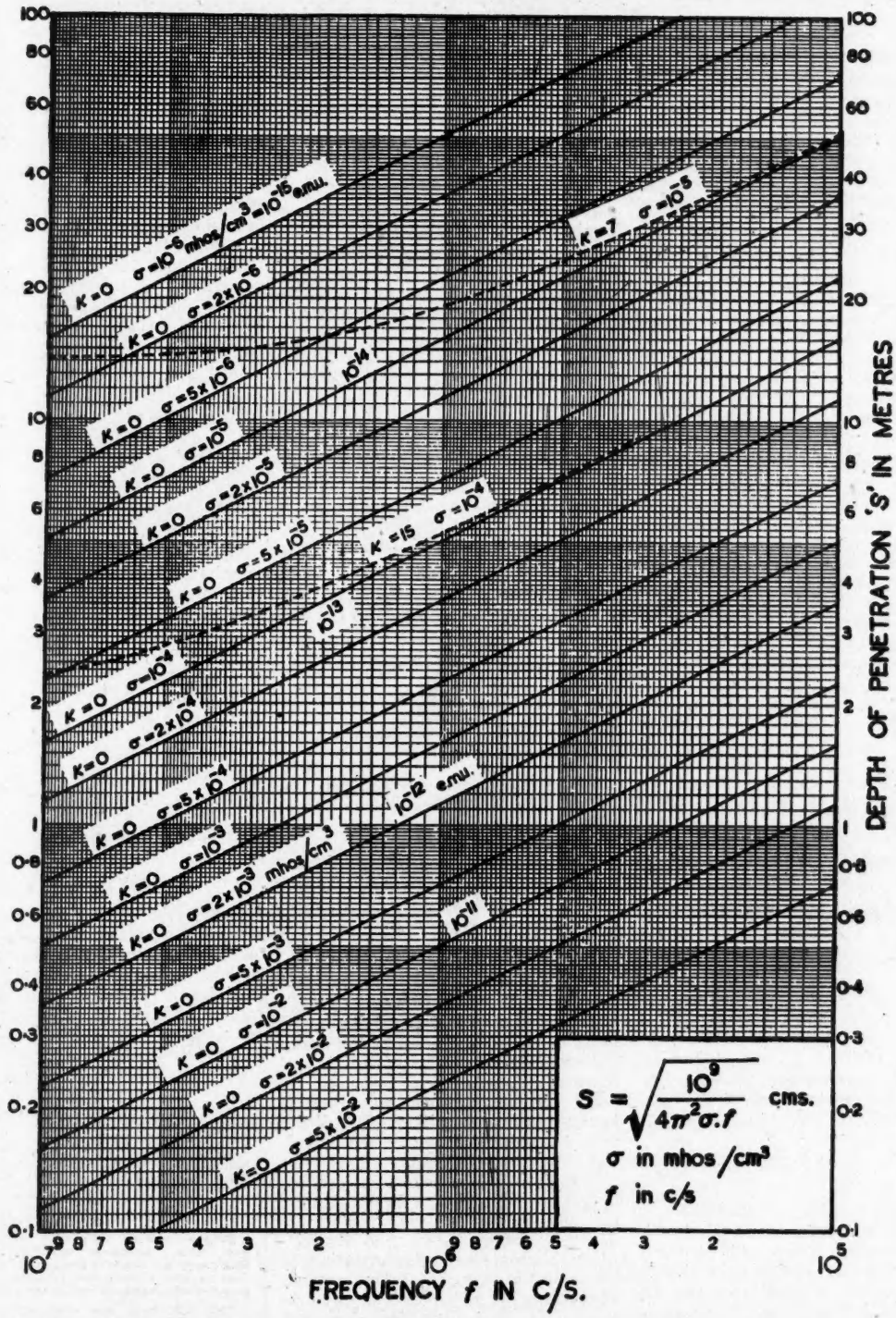


Fig. 6 Depth of Penetration of ground currents into a homogeneous soil of conductivity σ. The value of S gives the depth at which the current is .368 of its surface value. At a depth 4S the current is only 2 per cent. of its surface value.

Buried Wire Ground Systems

In Part II Data Sheet No. 53 it was shown that for the case of a perfect ground (infinite conductivity) the radiated field strength at one mile for one watt input did not drop appreciably by reducing the aerial length from a quarter wavelength to very small dimensions. The reduction in aerial length is, however, accompanied by a rapid drop in the radiation resistance, and with a finite ground conductivity a stage can soon be reached when the radiation resistance becomes small compared with the ground losses expressed as a transferred resistance at the aerial. The above effect is particularly marked in the case of short grounded aerials.

The effect of ground losses due to poor conductivity can be reduced by the use of either a counterpoise ground system or a system of buried wires. The latter system is in universal use in the case of broadcast stations and consists of a number of equally-spaced radial wires buried near the surface of the earth. The ratio of the current in the ground to the current in the wires is given by

$$\frac{I_g}{I_w} \approx j\frac{120}{\lambda}\sigma\left[\frac{x}{n}\right]^2\left\{\log_e \frac{a}{\pi}\left(\frac{n}{x}\right) - 0.5\right\} \quad \ldots\ldots\ldots (39)$$

where $j = \sqrt{-1}$

λ = wavelength in metres

σ = ground conductivity in mhos/cm³

n = number of equally spaced radials

a = radius of wires in ground system

I_w = current in single wire × number of wires.

From the above expression it will be seen that the earth current proper leads the current in the wires by 90 electrical degrees.

The current actually flowing in the earth expressed in terms of the total earth current is then given by

$$\left|\frac{I_g}{I_x}\right| = \left|\frac{1}{1 + I_w/I_g}\right| \quad \ldots\ldots\ldots (40)$$

While with the buried wires the current distribution in the ground will not be identical to that with the wires absent, if we assume that the change in distribution is small we can rewrite equation (35) as

$$\frac{dW_x}{dx} = \frac{I_g^2}{2\pi x\sigma S} \quad \ldots\ldots\ldots 41)$$

$$= \left|\frac{I_g}{I_x}\right|^2 \left|\frac{I_x}{I_o}\right|^2 \frac{I_o^2}{2\pi x\sigma S}$$

Power Losses

Fig. 4 illustrates the distribution of the power lost per unit length for a grounded quarter wave and eighth wave aerial above a ground with a conductivity of 2×10^{-14} e.m.u. or 2×10^{-5} mhos/cm³ with an earthing system of 15 wires 0.4 wavelengths long. The curves are drawn for a radiated power of 1 watt and a wavelength of 100 metres. The area under the curves represents the power lost in the ground, in the case of the quarter wave aerial this is 45 per cent. of the radiated power while for the eighth wave aerial 74.5 per cent. of the radiated power is lost in the ground. With the ground system inincreased to 113 radial wires each 0.4 wavelengths long the power lost in the ground system is negligible.

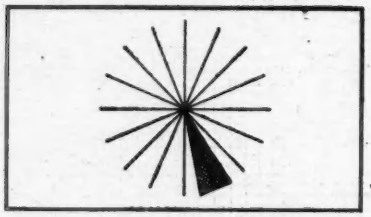


Fig. 5

While long radials are beneficial in reducing ground losses when a large number of radials is employed, little benefit will be derived by the use of unduly long wires when the number of radials is small. The reason for this will be evident from Fig. 5 where the shaded area represents the ground area serviced by each radial. As we proceed away from the aerial the boundaries of the shaded zone become more and more distant from the radial wire and therefore less of the total zonal earth current flows in the wire. The smaller the number of radials the shorter the radial wire required to reach the stage when any further increase in length will produce little extra current flow due to the extension.

The quantitative effect of radial length can be obtained from equation (39) and the reader is referred to the paper by Brown Lewis and Epstein where a great deal of information is given on the effect of various ground systems on the radiated field strength and aerial resistance for grounded aerials up to a quarter of a wavelength long and frequencies up to 3 megacycles/sec.

APPENDIX

The previous analysis is limited by ignoring the displacement current in the ground in considering the depth of penetration of the earth currents in the ground. The assumption limits the maximum frequency and dielectric constant, for any given ground conductivity, for which the simple theory is applicable.

Smith-Rose has given the following expression for the amplitude of the ground current $|I_s|$ at a depth "s" below the surface in terms of the amplitude of the ground current I_e at the surface:—

$$\left|\frac{I_s}{I_e}\right| = \exp.\ -\left(2\pi\frac{s}{\lambda}\right)p \quad \ldots\ldots\ldots (42)$$

where $p^2 = \frac{\sigma}{f}\sqrt{\left(\frac{K^2f^2}{4\sigma^2}+1\right)} - \frac{K}{2}$ (43)

where K and σ are in e.s.u. and $\mu = 1$. Expressing again the depth of penetration s as the value of S required to reduce the current to $1/e$ of the surface value we have

$$s = \frac{\lambda}{2\pi p} \quad \ldots\ldots\ldots (44)$$

$$s = \frac{\lambda}{2\pi\sqrt{\frac{\sigma}{f}\left(\frac{K^2f^2}{4\sigma^2}+1\right)} - \frac{K}{2}} \quad \ldots\ldots (45)$$

(The conductivity in different equations is given in whatever system of units that makes for a least cumbersome expression. It is hoped that the provision of the conversion table in last month's issue will avoid any confusion. 1 e.s.u. $= c^2 \times 10^{-9}$ mhos/cm³ $= 9 \times 10^{11}$ mhos/cm³).

In Fig. 6 are plotted a series of curves giving the depth of penetration for homogeneous soils of various conductivity as calculated by equation (34). In addition the depth of penetration for two types of soil calculated by equation (45) are given for comparison.

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"Phase and Magnitude of Earth Currents near Radio Transmitting Antennas," by G. H. Brown, *Proc. I.R.E.*, Feb., 1935.

"Ground Systems as a Factor in Antenna Efficiency," by G. H. Brown, R. F. Lewis and J. Epstein, *Proc. I.R.E.*, June, 1937.

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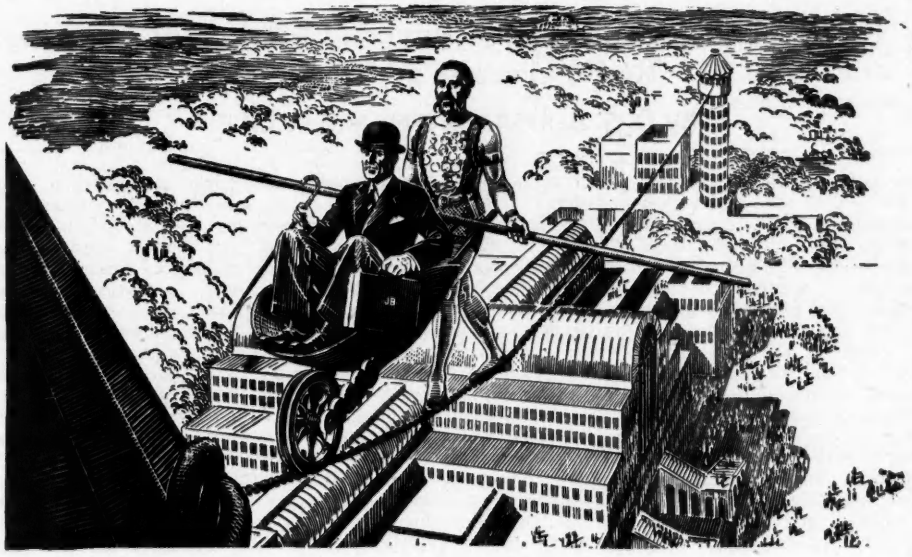

Industrial tight-rope

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Simplifying Symbols

Proposals for a Simplified Universal Method of Drawing Radio Circuits and Symbols

By D. S. B. SHANNON, M.Brit.I.R.E.

TO the radio engineer, whatever his nationality, the theoretical circuit diagram is an international short hand for conveying radio ideas and knowledge. Certain symbols vary slightly in different countries, but the general fundamental principle remains the same, and can be understood by all those versed in the art. Even though they do not speak the same language, each can convey to the other his ideas by means of a few symbols sketched roughly on a piece of paper, and although the symbols may differ in detail from country to country the meaning as a whole is clear. An American engineer may depict a valve thus, ; a British engineer may show the same valve this way, and a French may show it like this, all slightly different but perfectly clear in meaning to the radio engineer.

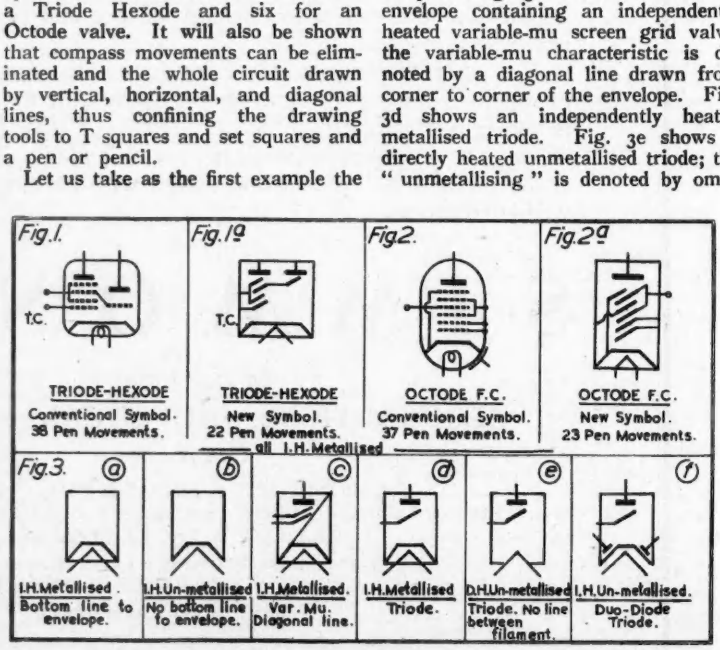
A resistor is shown in some continental countries thus -∿∿-, and in Great Britain and America like this -▭-, but both convey the same meaning when incorporated in a theoretical circuit diagram.

But has one considered the radio draughtsman's side of the picture? The research engineer usually presents him with a rough sketch of the proposed circuit, and the draughtsman is left to interpret the rough symbolic sketch in a neat working blue print. The engineer can diagram his circuit in a matter of minutes, and he may use a number of variations of the symbol code, but the draughtsman may take several hours, or even days, to produce a neat circuit layout

For some considerable time the author has given a great deal of thought to this problem of circuit diagram simplification, and now believes he has evolved a method of circuit drawing which, if adopted, could become an internationally accepted standard with advantage to all concerned. The engineer, of whatever nationality he may be, may still produce his rough sketch, using if he likes the present variations of symbols, but the draughtsman who puts the sketch into its final form will have his time cut down by an enormous extent, and all final drawings will be produced to one standard symbol code, easily understood at a glance by any radio engineer.

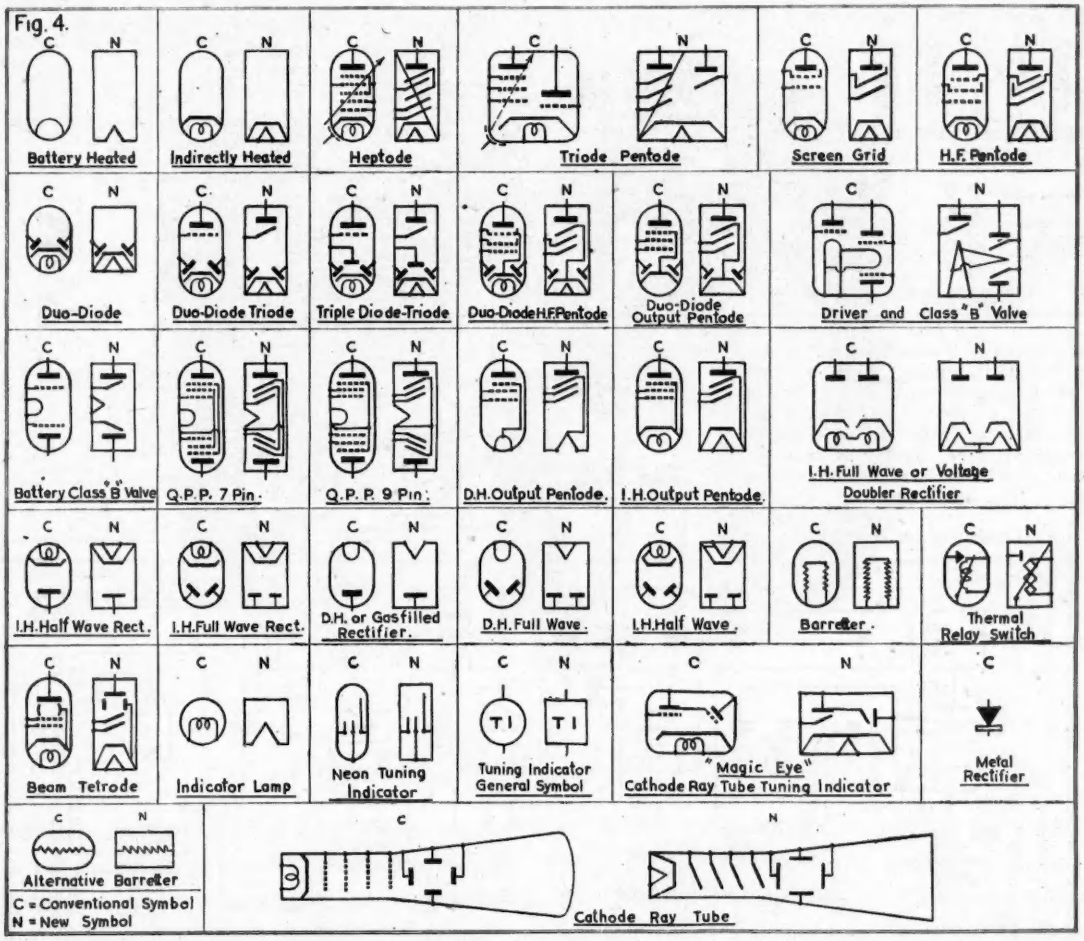
Previous attempts at standardisation still involved the draughtsman in unnecessary work. The main items in terms of time loss are the use of the compass, and the formation of the valve grid symbol, which is usually written as a series of short lines or dots or a zig-zag line (American practice). Actually, the zig-zag line is more easily drawn than the dotted form of grid symbol, and some may even prefer it to the type the author is about to suggest. The dotted symbol, although apparently very simple looking, - - - -, involves the draughtsman in three or four separate operations, i.e., he must lift his pen three or four times from the drawing, and in the case of a multigrid valve such as the Triode-Hexode or the Octode, the drawing of the grids alone involves at least fifteen to eighteen separate movements of the pen, whereas, it will be seen later, the author's method cuts this operation down to five movements for a Triode Hexode and six for an Octode valve. It will also be shown that compass movements can be eliminated and the whole circuit drawn by vertical, horizontal, and diagonal lines, thus confining the drawing tools to T squares and set squares and a pen or pencil.

Let us take as the first example the Triode Hexode valve, Fig. 1 showing the conventional symbol. Thirty-eight pen movements are required to form this symbol, consisting of 7 compass movements (heater and envelope corners), 7 vertical lines, 21 horizontal lines and 3 diagonal lines. Fig. 2 shows the same symbol drawn to the author's method, the pen movements being reduced to twenty-two lines consisting of 5 vertical lines, 8 horizontal lines and 9 diagonal lines. No compass is required, yet the symbol remains substantially the same. Fig. 1a and 2a illustrate the same methods applied to the Octode valve with a similar saving of operations and time. Fig. 3 a, b, c, d, e, f illustrates a further expansion of the scheme. Fig. 3a shows a metallised envelope with an independently heated cathode. The metallising is denoted by the bottom horizontal line of the envelope. Fig. 3b shows the same arrangement with an unmetallised envelope, denoted by omitting the bottom line of the envelope. Fig. 3c shows a metallised envelope containing an independently heated variable-mu screen grid valve; the variable-mu characteristic is denoted by a diagonal line drawn from corner to corner of the envelope. Fig. 3d shows an independently heated metallised triode. Fig. 3e shows a directly heated unmetallised triode; the " unmetallising " is denoted by omit-



Figs. 1 and 2. Standard symbols and the author's symbols compared to show saving in drawing time.
Fig. 3. Simplified valve symbols.

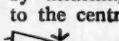
Fig. 4.



ting the bottom line of the envelope between the filament legs, and Fig. 3f shows an unmetallised independently heated duo-diode-triode.

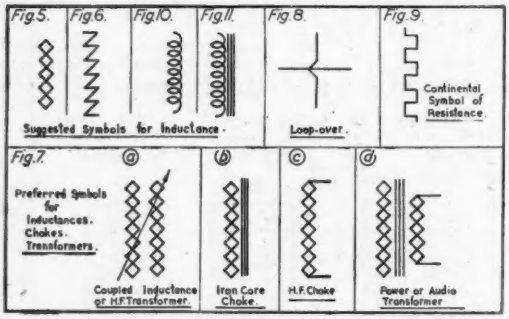
The foregoing examples illustrate very well the basic simplicity of the scheme. These basic principles, of course, apply to all types of valves from diodes to multigrid and special types. Fig. 4 shows a number of typical valves drawn conventionally and compared with the equivalent new symbol, also special types such as barretters, magic eyes, neon tuning indicators, etc.

Before dealing with the other types of symbol, such as chokes, transformers, resistances, etc., let us refer to the method chosen to illustrate the grid. As already stated, the dot method has definite disadvantages. The zig-zag method is a little easier to draw, specially when drawing freehand, but when drawing on the board it still involves more work than is necessary. The diagonal line method now suggested was therefore finally decided upon as being the most simple solution to this problem, and if drawn with a slightly thinner stroke than the anode no confusion as to its meaning is likely to arise. It is both neat and simple, and a great time-saver.

With regard to the other symbols, the method of illustrating capacity does not in the author's opinion, require improvement, and to avoid confusion the zig-zag resistance symbol is retained, although a more simple method might be used: for example, a very tapered triangle, thus and a potentiometer would be shown by attaching the conventional arrow to the centre of the triangle herewith  . Readers and critics may care to offer further suggestions for an improved resistance symbol. We now come to the question of inductances and transformers, which involve the draughtsman in a considerable amount of compass work. It was at first intended to use the continental "square loop" method of illustrating a resistance as the new symbol for inductance, but on second thoughts it was realised that this would be liable to cause confusion, particularly among continental engineers.

Figs. 5 and 6 illustrate the alternative methods which might be used. Fig. 5 is less likely to be confused with the present symbol for resistance. Chokes and transformers would also be drawn, using the Fig. 5 and 6 method with the addition of the conventional lines denoting the use of iron cores.

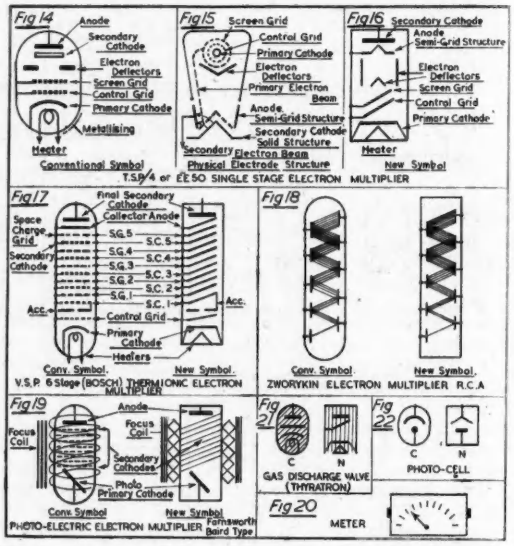
Fig. 7 a, b, c, d denote the new symbols for inductance: Fig. 7a, coupled inductance; Fig. 7b, iron cored low frequency choke; Fig. 7c, high frequency choke, and Fig. 7d, audio frequency or power transformer. The latter may be, of course, shown with voltage tappings in the usual manner when necessary. Fig. 7a may be shown as a single inductance, tuned or untuned by a vari-



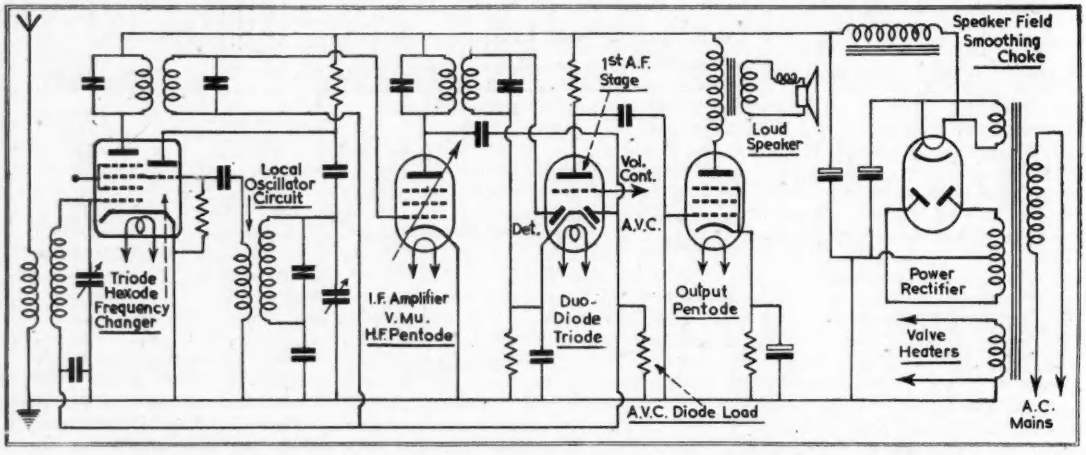
able capacity or may be used to denote an H.F. choke. Figs. 10 and 11 show conventional symbols for air and iron core inductance. Fig. 8 denotes the new symbol for a loop-over connexion; here, again, it will be noted that two diagonal lines are used to form the loop.

(*Continued on p.* 294.)

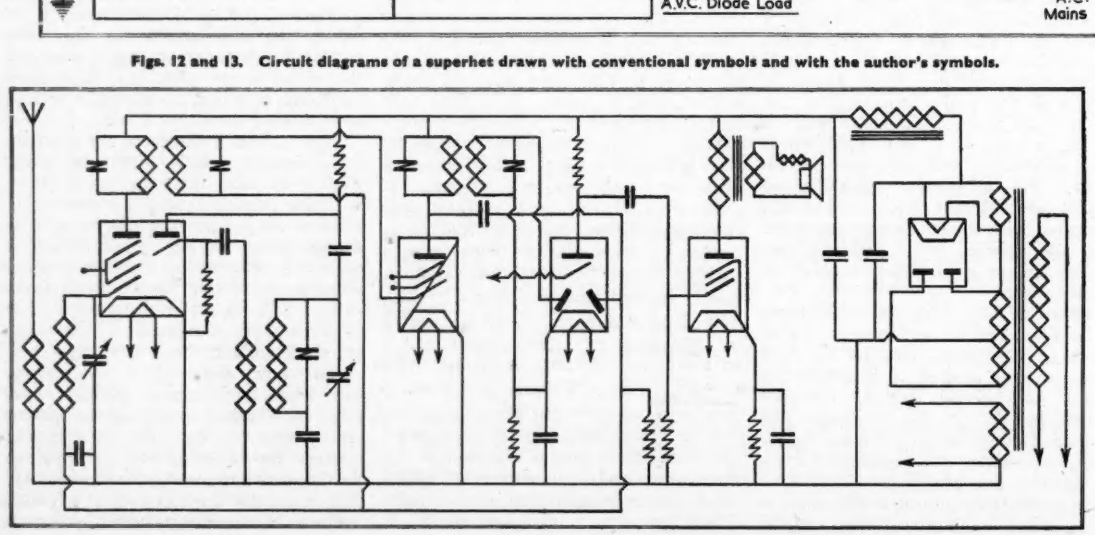
Figs. 5 to 11. Suggested symbols for components.



Figs. 14 to 22 (right). More complex symbols.



Figs. 12 and 13. Circuit diagrams of a superhet drawn with conventional symbols and with the author's symbols.



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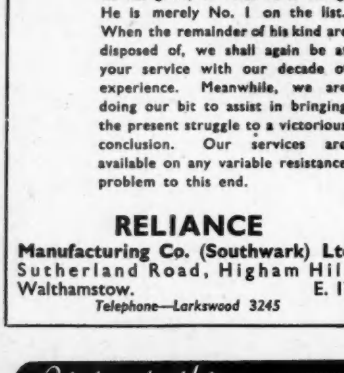

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(*Continued from p.* 292.)

Where meters are inserted in a circuit the square formation of the case may be used to avoid the use of a compass (*see* Fig. 20), again saving time by avoiding the change from one drawing instrument to another.

Figs. 12 and 13 are two skeleton circuit diagrams of a modern broadcast superheterodyne receiver. For the sake of simplicity and clarity, the circuit has been shorn of complications such as wave-band switching, filters, R.F. and additional I.F. stages, negative feed back, etc., and is intended purely to illustrate the new circuit diagram drawing in comparison with the conventional method.

Another example where an improved method of depicting symbols shows to advantage, is in the case of the Mullard-Phillips secondary emission valves known as types T.S.P.4 and E.E.50. Fig. 14 shows the manufacturers' symbol for this type of valve. If we read the symbolic diagram as literally shown it would appear that the secondary cathode is placed between the anode and the screen grid. This, of course, is not so in the physical construction of the valve, as will be seen from Fig. 15.

In actual construction the anode is placed between the screen-grid and the secondary cathode, half the anode being in the form of a grid structure, and the other half being of solid plate construction.

Fig. 16 shows the author's proposed symbol drawing for this type of valve, which gives a more symbolic picture of the physical electrode construction, and the reader is more clearly able to visualise the passage of the electron stream from the primary cathode to the secondary cathode, and the secondary emission path to the anode.

Other types of electron multiplier symbols are suggested in Figs. 17, 18, 19. Figs. 21 and 22 illustrate a Thyratron or gas discharge triodes and a photo-electric cell respectively.

In conclusion, whilst admitting that the new scheme suggested is open to further improvement and enlargement, it will no doubt be agreed that the basic principles here suggested would greatly simplify circuit drawing. particularly, as already mentioned, from the draughtsman's point of view. From recent correspondence in the technical journals it would appear that the author is not alone in thinking that the time has arrived for overhauling the older methods of circuit drawing which have held sway for very many years.

December Meetings

Institution of Electrical Engineers

Wireless Section

The next meeting will be held on December 1, at 5.30 p.m. Papers will be read by T. S. Littler, Ph.D., M.Sc., on "Electrical Hearing Aids," and also by C. M. R. Balbi on "A Basis for the Prediction of Performance of Hearing Aids."

Students' Section

The next meeting will be held on December 15, at 6.30 p.m. The address will be given by Mr. K. J. Easton on "Electrical Transmission of Sound."

North-Western Centre Wireless Group

A meeting of the above Group will be held at the Engineers' Club, Albert Square, Manchester, on Friday, December 10, at 6 p.m. A paper on "Amplifying and Recording Technique in Electro-Biology with special reference to the Electrical Activity of the Human Brain" will be read by Messrs. G. Parr and W. Grey Walter.

Institute of Physics

On December 10, at 6 p.m., a meeting will be held at the Reid-Knox Hall of the British Institute of Radiology and Rontgen Society, when E. H. Rayner, M.A., Sc.D., M.I.E.E., F.Inst.P., of Messrs. General Electric Company, Ltd., will give a lecture on "The Electron Microscope," after which the meeting will be open for discussion.

Brit. I.R.E.

The next meeting of the above will be held on December 15, at 6.30 p.m., at the Institution of Structural Engineers, 11 Upper Belgrave Street, London, S.W.11. A paper on "Selective Methods in Radio Reception," will be read by E: L. Gardiner, B.Sc.

R.S.G.B.

A meeting will be held on December 18, at the I.E.E., when a lecture will be given by R. L. Smith Rose, D.Sc., Ph.D., M.I.E.E., D.I.C., A.R.C.S., entitled "Measurements in Radio Experimental Work." The Annual General Meeting is convened for 2 p.m., and the lecture will follow.

Association for Scientific Photography

On December 18, at 2.30 p.m., a display of scientific apparatus will be held jointly with the Scientific and Technical Group of the Royal Photographic Society. The meeting will be at the headquarters of the Royal Photographic Society, 16 Princes Gate, London, S.W.7. Tickets of admission may be obtained from the Editor of this journal, 43 Shoe Lane.

British Kinematograph Society

On December 15, at 6 p.m., the Presidential Address will be given by A. G. D. West, M.A., B.Sc., F.R.P.S. The subject will be "Modern Physics and Kinematography."

The C.-R. Tube in Mechanical Testing (*Concluded from p.* 280.)

used for the direct measurement of accelerations. A very important feature results from the fact that the piezo electric phenomenan is reversible. With suitable excitation the quartz crystal can be used as a generator of mechanical oscillations. By increasing the frequency to ultrasonic range the vibrations acquire directional characteristics and form a beam which is normal to the surface to which it is applied. The resulting waves suffer reflection when passing from one medium to another of different density—it is almost complete reflection between a solid air interface—and can thus be applied in testing for flaws within materials. Often when examining small specimens the method of relative timing of the waves is used. When using the echo-sounding principle the excitation is obtained by means of a pulse generator and the quartz crystal itself can be used as a detector of these waves.

Rochelle salt is really less adaptable for application in mechnical tests, but because of its much greater sensitivity it has been used in certain static tests, such as surface analysis. It is mechanically less stable and loses sensitivity with temperature, it is subject to fatigue and hysteresis, and, finally, its response is not proportional to pressure.

Magneto-Striction

When a mechanical stress is applied to certain magnetic materials, chiefly nickel, nickel-iron and cobalt-iron alloys, their magnetic characteristics are altered. This type of device is not much used because of the following disadvantages: It is subject to eddy-current and hysteresis. The former is reduced by design and the latter by subjecting the element to an intense A.C. field before use. When under tension the law of variation is sensibly linear. It saturates rapidly under compression and possesses reduced sensitivity under hydrostatic pressure and a non-linear law.

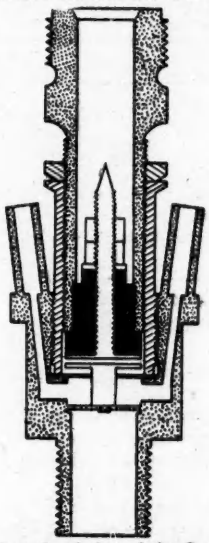


Fig. 7. A sectional view of the Consor-Dodds capacitance sparking plug type Pressure Unit for Engine Indicator work.

Conclusion

It is clear from the above survey that a high degree of finality sufficient to meet all practical requirements can to-day be obtained with a cathode-ray oscillograph, or more correctly, the indicating and recording section of the electronic equipment required for mechanical investigations.

Although theoretically it is possible with present-day technique to realise the same degree of finality with the pick-up device and associated apparatus, this stage has not yet been practically achieved and is therefore not yet obtainable.

As a result the application of the cathode-ray oscillograph and the choice of a suitable pick-up device to a given problem is still a matter which requires considerable circumspection. Even though the choice could be determined on technical grounds alone, in practice it is much more dependent on the type of cathode-ray instrument available, the facility or otherwise of designing or making the necessary auxiliary apparatus, and, above all, the mechanical and electrical difficulties in the design and application of the pick-up device itself.

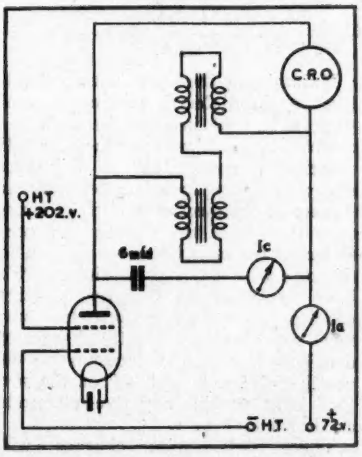
A "Slow-Motion" Oscillator for Class Demonstration

By C. H. BULMAN*

THE following very simple piece of apparatus was constructed to demonstrate the nature and the phase relation of the currents present in an oscillatory circuit when such a circuit is included in the anode circuit of a valve, the valve supplying the power to maintain the oscillations. Such a circuit has hundreds of applications in radio practice, but under working conditions the oscillations take place at a speed almost beyond human comprehension. By using very large values of inductance and capacity, however, it is possible to slow up the process to about half-a-cycle per second instead of several million cycles per second. Under these conditions students are able to examine the slowly rising and falling currents, their magnitude and phase relation, by means of ordinary measuring instruments. The effect of changes of the inductance or capacity upon the frequency can also be clearly observed since the frequency is slow enough to be counted by watching the meter deflections. By adding a cathode-ray oscilloscope, as shown in the diagram, the spot will be seen to slowly trace out the shape of a sine curve when the slowest time-base setting is used. This will help to demonstrate the principle of the oscilloscope very clearly since the frequency of oscillation is too slow to produce the optical illusion of a continuous trace.

In order to obtain a very large inductance with a value in the region of 100 henrys, two commercial intervalve transformers were used with all the windings in series. Naturally, care must be taken to see that the windings are so connected to assist one another. Any other form of inductance would do equally well.

The meter measuring the circulating current in the oscillatory circuit I_c must be an A.C. milli-ammeter with a range of 0.20 milliamps, and the anode current (I_a) meter has a similar D.C. range.



Both meters should be mounted close together to facilitate their deflections being watched simultaneously.

* St. Helen's Technical College

High Frequency Therapy

Part IV.—The Electric Field in a Dielectric

by W. D. OLIPHANT, B.Sc., F.Inst.P.*

WE have already studied the phenomenon of dielectric polarisation and the configuration of the lines of force in a simple condenser made up of two electrodes completely surrounded by air. It is now necessary to investigate in some detail how the electric field distribution is affected by the insertion of a complex dielectric medium into the condenser field.

Electric Induction or Displacement

Take a simple parallel plate condenser of separation d and consider what happens when the dielectric medium is firstly air and secondly a substance of dielectric constant ϵ. (The dielectric constant for air is taken to be unity.) Assume unit cross-sectional area and let V be the potential difference between the electrodes and σ_1 be the surface density of electrification. Then we have for the air condenser:

$$4\pi\sigma_1 = \frac{V}{d} = E \quad \ldots\ldots\ldots\ldots\ldots (1)$$

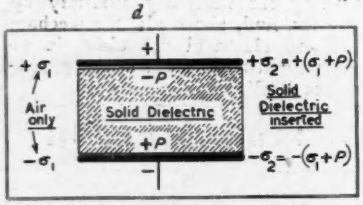


Fig. 1.

Maintaining the same potential difference, the dielectric medium of constant ϵ is now inserted between the electrodes, and we assume for all practical purposes that an infinitesimally thin air-gap exists between the surface of the electrodes and the boundary surface of the dielectric, a condition which may be assumed even in the case of a gaseous medium. We have seen that the dielectric will become polarised and the boundary surfaces will therefore acquire charges of density $-P$ on the surface next to the positive electrode and $+P$ on the surface next to the negative electrode as shown in Fig. 1.

These polarisation charges will induce equal and opposite charges on the electrodes thus increasing their surface charge density which will now become σ_2 where

$$\sigma_2 = \sigma_1 + P \quad \ldots\ldots\ldots\ldots\ldots (2)$$

* University of St. Andrews.

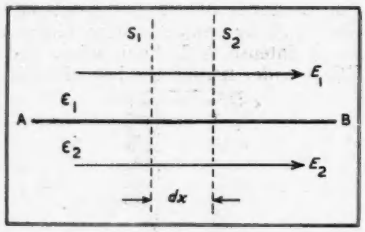


Fig. 2.

Now $\sigma_2 = \epsilon.\sigma_1$ and so from (1) we can write

$$\epsilon.\sigma_1 = \sigma_1 + P$$

$$\text{or } \epsilon.\frac{V}{4\pi d} = \frac{V}{4\pi d} + P$$

from which we get

$$\epsilon = 1 + 4\pi.\frac{P}{E} = 1 + 4\pi K. \quad \ldots\ldots (3)$$

where K is known as the electric susceptibility of the medium and is equal to the ratio of the polarisation to the applied field.

Multiplying (3) by E we get

$$\epsilon.E = E + 4\pi P = D \quad \ldots\ldots (4)$$

where D is the dielectric displacement or electric induction in the medium.

From the foregoing, it is easy to see how, when the electrode difference of potential is maintained constant, the effect of introducing the solid dielectric in place of the air is to increase the charge on the plates. On the other hand, if the electrode charges are maintained constant, then the insertion of the dielectric is associated with a reduction in the potential difference.

Refraction of Lines of Electric Force

In any composite dielectric the lines of force must pass from one medium to another, and it is necessary to determine the law which governs the passage of lines across an *uncharged* interface between two dielectric media. There are three cases which will now be considered in turn.

Case 1. *Applied field parallel to interface.*

Consider the interface AB shown in section in Fig. 2 between two isotropic media of dielectric constants ϵ_1 and ϵ_2 and let the fields in each medium be E_1 and E_2. Take any two equipotential surfaces S_1 and S_2 normal to the interface and distant dx apart. These surfaces are parallel and the potential difference between them in the first medium is E_1dx, and in the second medium is E_2dx. Now these must be equal, and so E_1 must be equal to E_2. In other words, we have established the first boundary condition that the *tangential* component of the electric intensity is continuous across the interface.

Case 2. *Applied field normal to interface.*

The arrangement in this case is shown in Fig. 3, and we here consider a small closed surface whose ends are of equal area a and are parallel to the interface, and whose sides are normal to it. On applying Gauss's Theorem to this surface, and bearing in mind the fact that no charge exists on the interface, we get that

$$\epsilon_1E_1 = \epsilon_2E_2 \text{ or } D_1 = D_2$$

We have thus obtained a second boundary condition in that at any point on an uncharged interface the normal component of the electric displacement is continuous.

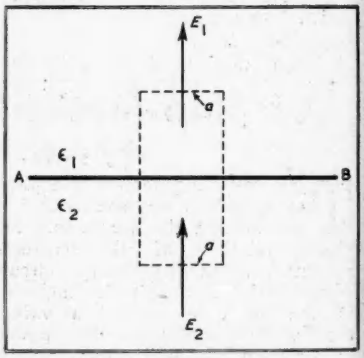


Fig. 3.

Case 3. *Applied field at any angle to interface.*

This is the general case and depends for its solution on the application of the two boundary conditions already established. It is at once evident that for the above conditions to apply, the lines of force must be bent or refracted on traversing the interface. This is shown in Fig. 4.

The boundary conditions are satisfied when

$$E_1 \sin\theta_1 = E_2 \sin\theta_2$$

and

$$D_1 \cos\theta_1 = D_2 \cos\theta_2$$

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whence we obtain

$$\epsilon_1 \cot \theta_1 = \epsilon_2 \cot \theta_2 \quad \ldots\ldots\ldots\ldots \quad (5)$$

Furthermore, since the parallel components are in the same direction in each medium, E_1 and E_2 are in the same plane normal to the interface.

It is interesting to compare the refraction of electric intensity with that of light. In the former case the electric lines are bent *away* from the normals at the points of incidence at the interface on entering the denser medium (higher dielectric constant), while in the latter case the rays of light are bent *towards* the normals on entering a denser medium (higher refractive index). The equation corresponding to (5) for optical refraction were μ is the symbol for refractive index is

$$\mu_1 \sin \theta_1 = \mu_2 \sin \theta_2.$$

Simple Examples of Electric Refraction

In Fig. 5 we have the field configuration associated with a point charge q which is situated in front of a plane dielectric boundary AB. By

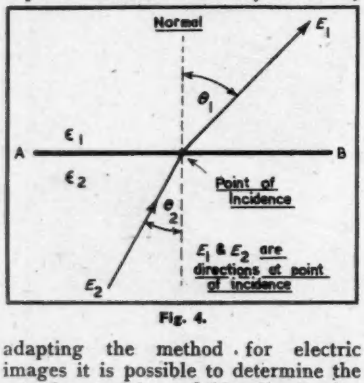

Fig. 4.

adapting the method for electric images it is possible to determine the actual resulting field distribution which may be briefly summarised as follows. Let the point charge be situated in a dielectric medium of constant ϵ_1 and distant a from the boundary surface of an infinite dielectric medium of constant ϵ_2. The field in the *first* medium is drawn from a system made up of the original charge and its virtual image in the second medium. This image is situated as far behind the boundary surface as its object charge is in front and is of magnitude

$$\frac{(\epsilon_1 - \epsilon_2)}{(\epsilon_1 + \epsilon_2)} \cdot q.$$

The field in the *second* medium is that which would be produced by replacing the original charge by one of magnitude $\frac{2\epsilon_2}{\epsilon_1 + \epsilon_2} \cdot q$. In this latter case the lines will be linear and will be radial with respect to the charge position.

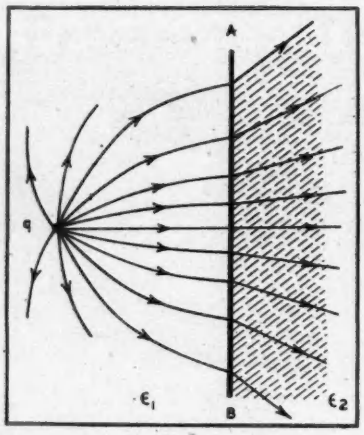

Fig. 5.

The actual field due to the original charge is thus a combination of the two portions and it will be found that the angles which the lines make with the normals to the boundary surface are in accordance with Eqn. (5).

Another case which is readily calculable is that of a homogeneous dielectric sphere of radius a and dielectric constant ϵ_1 placed in a medium of dielectric constant ϵ_2 in which there originally existed a uniform field of strength E_0.

It is found that the field within the sphere is uniform and is equal to $\left(\frac{3\epsilon_2}{\epsilon_1 + 2\epsilon_2}\right) \cdot E_0$ which approaches the value $\frac{3}{2} E_0$ for $\epsilon_2 >> \epsilon_1$, and becomes very small if $\epsilon_2 << \epsilon_1$.

The field outside the sphere is that which would be produced by a dipole situated at the centre of the sphere and of calculable moment.

The field configuration is shown in Fig. 6 and again equation (5) is satisfied at the surface of the sphere.

Many other solids of revolution lend themselves readily to mathematical treatment and their solutions are of great value to the research worker. In therapeutic work, however, one must satisfy oneself with a knowledge of the fundamentals and apply them as well as possible since the dielectric "bodies" are by no means regular.

Field Configuration as a Function of Electrode Arrangement

In successful clinical practice it is a necessary condition that the field density be a maximum within the affected organ or part of the body which requires treatment. This is achieved by suitable choice of electrodes and by so placing the body with respect to them that the desired field concentration is produced, the heating effect being proportional to the square of the field strength. In view of the heterogeneous nature of the human body, it is only possible to approximate to the correct desired field distribution, but by taking the very simple case of a homogeneous and regular body it is possible to develop certain basic rules.

If we consider first of all the field between a pair of similar-sized and planar electrodes, then it is well known that the field is uniform and a maximum at the centre. The insertion of a body placed symmetrically with respect to both electrodes will thus ensure maximum heating in the central zone between the electrodes. With adequate separation (that is to say, with a suitable air gap) depth of heating and homogeneity of the field is ensured. If the electrodes are unevenly placed with respect to the body, then concentration of energy would take place at the nearer electrode,

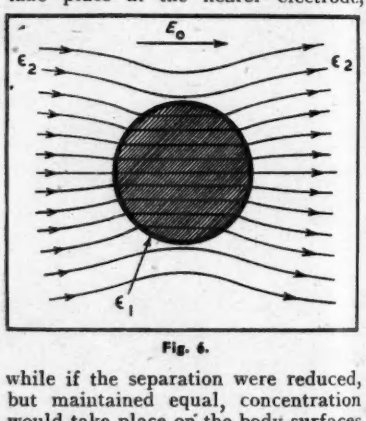

Fig. 6.

while if the separation were reduced, but maintained equal, concentration would take place on the body surfaces adjacent to both electrodes. The presence of a piece of metal between the body and one of the electrodes would bring about enormous field concentration in its vicinity with consequent serious burning of the patient. It is thus of vital importance that the patient be searched for any metal objects either in the make-up of the clothing or in the pockets before treatment is started.

If it is desired to bring about considerable superficial concentration of heat, then resort is made to a smaller electrode which is used at small separation in conjunction with a larger electrode placed at greater separation. The use of too small electrodes brings about a superficial concentration in very large bodies, the field density being considerably greater at the surface than in the centre of the body.

In the transverse or lateral treatment of, say, a limb, we have a choice

TABLE I

Material	Specific Resistance (ohm cm.)
Blood (human)	200—300
Urine (human)	38—180
Pus (dog)	520
Bile (rabbit)	65
Skin (rabbit)	11,000
Heart (horse)	600—900
Brain (dog)	900—1,000
Bone (frog)	2200
Liver (frog)	220
Muscle (striped, dog)	1,100—2,000
Muscle (unstriped, dog)	200—600
Nerve (ox)	150—260
Protoplasm	126—800
Serum (ox)	75—125

of two possible methods. If we wish to work with fairly small separation, then for even distribution of the field it is necessary for the electrodes to be shaped approximately to the part under treatment. These electrodes should not be too large as otherwise the edges will come close together with resulting field concentration in that vicinity. If it is desired to use planar electrodes, then the separation must be much greater, and the resulting field diagram would be similar to that shown in Fig. 6. With too close spacing in this latter method, concentration would take place on the limb surfaces close to the electrodes while the internal heat distribution would be very uneven, being a maximum across the centre of the limb.

In the treatment of a small part of a large body, the electrodes being thus relatively small and placed more or less side by side, it is essential to ensure that they are not so placed as to create field concentration in the region between the adjacent electrode edges. Electrodes placed on one side of a body obliquely to each other will bring about energy concentration in the region of the body between the nearer edges.

In the treatment of irregularly shaped bodies such as the head, or when the surface of the body is covered with pimples and furuncles, it is necessary to work with wide separation to avoid bringing about excessive field concentration at the points near the electrodes. This at the same time ensures a uniform heating effect at greater depth. Another example of this body point effect would be in the simultaneous lateral treatment of both knee joints. In this case the electrodes would be placed outside the joints and great concentration would occur on the insides. This is overcome by making the patient grip a towel or rubber pad between the knees during treatment, thus producing the necessary body continuity for a uniform field.

The Electrical Properties of Biological Materials

The two electrical quantities which we are primarily interested in are specific resistance (or conductivity) and dielectric constant. We will see later how these quantities taken in conjunction with frequency define the energy absorption which will take place in the material. In determining the values of these quantities experimentally we are faced with many difficulties. Each biological material in itself is subject to wide variation in its structure; the mode of preparation will affect the measured values, and at high frequencies the containing membrane will contribute a very marked effect. Furthermore, the values will depend on whether or not the material is being examined by itself or in conjunction with other bodily functions. The subject is open to a vast amount of research, and we must not lose sight of the fact that malignant as well as healthy conditions of the body come within the scope of the subject.

The experimental values for the above quantities have been taken from *Grundriss der Kurzwellentherapie*, by by W. Holzer and E. Weissenberg, and are contained in the tables given on this page.

In Table I is given a selection of biological materials and the values of specific resistance are given for measurements made over a range of frequencies of from 10^4 to 10^8 cycles per second.

The outstanding feature of the above table is the wide range of values covered not only for the various materials between themselves, but also for any one given material. In protoplasm, for example, we have values ranging from 126 to 800 ohm cm. It must also be remembered that there is a very marked variation with change of frequency.

The human body consists both of electrolytes and dielectrics and the tissues may be taken as being made up of resistances and condensers connected in series and parallel. The effective capacitance is dependent on the dielectric constant which for an electrolyte is governed by its concentration. The variation of dielectric constant with frequency has already been discussed when we were considering anomalous dispersion.

In general, most biological substances have a dielectric constant of the same order as that for water where $\epsilon = 78.5$. Organs which are fatty or which contain air spaces have much lower constants of the order of from 10 to 30. Serum and proteins have probably the highest values being of the order of 85.

Holzer and Wiessenberg give values for certain materials, shown in Table II. In this table the wavelength in metres λ at which the measurements were made is also given.

In a study of electro-biology the changes in dielectric constant are intimately connected with such chemical processes as flocculation or coagulation, and also in the production and maintenance of electrical potentials in organisms.

(To be continued.)

TABLE II

Material	λ m	Dielectric Constant
Water	2.8	78.54
Brain	2.81	78.54
Liver	2.75	75.95
Spleen	2.78	77.6
Muscle	2.78	76.6
Kidney	2.76	76.2
Kidney, fat	1.16	13.6

Conferences

There is some curious twist in the business mind that makes it suspicious of the right answer.

Consider what happens to most problems that are tossed into a conference. The sound solution is almost always simple and obvious, but the regular practice is to struggle all the afternoon to find some compromise with the right way.

It seems to be accepted as evidence of the shrewd business mind to be able to so confuse and muddy a proposition that no one will ever think straight about it again.

—*Seen on the wall in somebody's office.*

Fluorescent Lamps

A Survey of Old and Recent Developments—Part IV : Conclusion

By R. NEUMANN, Dipl. Ing.

THE principal requirements which a satisfactory fluorescent lighting equipment must fulfil are: low striking voltage of the arc, a minimum of additional appliances which might cause trouble, long life of the tube and especially of the activated electrodes, reliable operation and a short time lag in attaining the full luminosity. From the commercial point of view, small dimensions, low initial costs, and high luminous efficiency must be added.

As may be gathered from the service suggestions given by Amick.[22]* and from a discussion which took place at the Royal Society of Arts a short time ago[21] starter troubles play quite an important and undesirable part in the operation of these light sources. Damage to the starting switch may, for instance, be caused if a fluorescent tube near the end of its life loses the emission from its electrodes. As was pointed out by J. N. Aldington in a paper containing much valuable information on the development of the "Sieray" fluorescent lamp of Siemens[23] a "blinking" or "hunting" effect may be noticed as the first sign of the need for a new lamp and in this case the old lamp should be replaced or switched off without delay. There are also quite a number of other causes for starter troubles. To avoid these and at the same time to fulfil all the requirements mentioned above, research work done within the last few years at the laboratories of the G.E.C., Ltd., Wembley, by Dr. M. Pirani and his colleagues[1] may well serve to bring about marked improvements in fluorescent lighting and in other gas discharge lamps.

Two distinct problems were treated separately, the solutions of both being combined to attain the desired results. One problem concerned the starting and maintenance of the glow discharge, the other concerned the safe transition from the glow discharge to the arc discharge. The first is mainly a physical problem related to the tube itself, especially in the avoidance of wall discharges, while the second is more of a physico-chemical nature and its solution was found by a specially devised activated electrode.

* *See* Bibliography to Part II, p. 205.

[23] J. N. Aldington, *Fluorescent Light Sources and their Applications*, Illuminating Engineering Society, Lecture, April 14, 1942.

Types of Starting Circuit

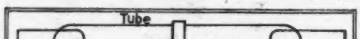

Fig. 6. Connexions of lamp with auxiliary electrode and induction coil.

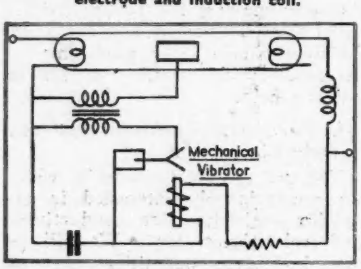

Fig. 7. Lamp with mechanical vibrator in coil circuit.

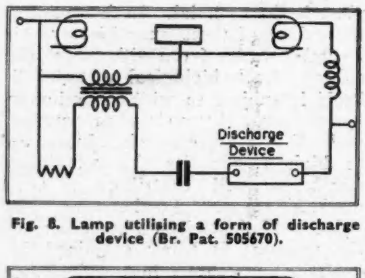

Fig. 8. Lamp utilising a form of discharge device (Br. Pat. 505670).

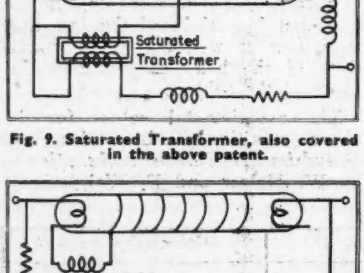

Fig. 9. Saturated Transformer, also covered in the above patent.

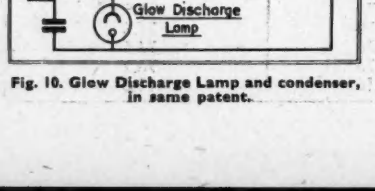

Fig. 10. Glow Discharge Lamp and condenser, in same patent.

Starting and Maintaining Glow Discharge.—As a forerunner of the present development a diagram of connexions is shown in Fig. 6.[21] Here an outer auxiliary electrode is placed midway between the main electrodes and connected to an induction coil "which causes the tube to ignite by the production of some ions and therewith the removal of negative wall charges." These wall charges would prevent the discharge between the main electrodes from starting even if sufficient ions are present in the gas or vapour. The function of removing the wall charges is performed by producing electric fields strong enough to produce ionisation by collision. The ions thus produced are attracted to the walls and neutralise the charges on them. The wall charges are apparently caused by diffusion of electrons and they occur in quite irregular patches. The temperature of the walls seems to play an important part. Although the induction coil used in connexion with the auxiliary electrode needs only a few watts, the voltage produced by it is largely in excess of the supply voltage and this is undesirable as the insulation of the whole outfit must be adapted to the highest occurring crest value of voltage.

Patent 505670 of G.E.C., Ltd., Pirani and Rüdenberg (1937) shows some alterations of the same principle. In Figs. 7-10 the auxiliary electrodes are either placed inside the tube or, as in Fig. 10, outside the tube in the form of a spiral of fine wire wound around the whole length of the tube, or a conducting coating painted on the envelope. In Fig. 7 a mechanical (reed) vibrator, in Fig. 8 a discharge device, in Fig. 9 a saturated transformer, and in Fig. 10 a glow discharge lamp shunted by a condenser, are connected in the primary circuit of the induction coil. The peak of the impulse voltage applied to the auxiliary electrode "does not exceed or even attain 10 times the r.m.s. voltage of the supply." But, as mentioned above, such an excess voltage is undesirable, and besides in all the examples shown in the figures auxiliary appliances are required which may cause trouble.

The fact that the power required for producing the impact voltage never

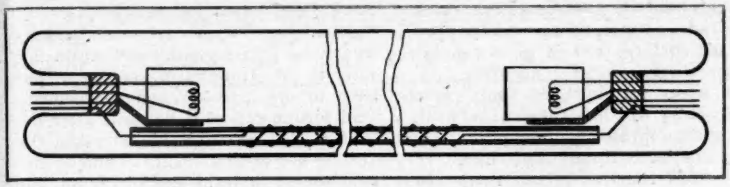

Fig. 14. Design for fluorescent tubular lamp—Pirani.

exceeds 10 watts and is often less than 1 watt makes this kind of connexion suitable for special services, *e.g.*, the control of flashing signs and the like for signalling purposes.

Some examples are given in the patent specification which show that the ratio of the open circuit r.m.s. value of the voltage to the running r.m.s. voltage may be as high as 0.66 or even 0.86.

According to patent specification 506919 of the same inventors and the same year the induction coil is replaced by a valve oscillator consisting of a back-fed thermionic triode with a resonance circuit connected between auxiliary electrode and earth. The oscillator is capable of applying a sinusoidal voltage of at least 6 Mc/s. to the auxiliary electrode. The latter is made broad in the centre and tapering at the ends so that the ionisation produced by it near the main electrodes is high enough, but not too strong so as to cause a large voltage drop of the auxiliary source and therewith impede the ionisation in the centre part of the envelope. Preferably the current of the auxiliary source is furnished without interruption although it would be sufficient to apply it only at the start of each half cycle of the main voltage. Fig. 11 shows the diagram of connexions.

In patent 517253 of G.E.C., Ltd., Bloch, Pirani and Prinz (1938) the conditions are discussed which are apt to make the auxiliary electrode most effective even if no valve oscillator is used. It should touch or approach very nearly the envelope over its whole length. As its effect is that of a condenser plate it should cover a considerable part of the circumference. But, of course, a compromise is necessary, as otherwise the electrode would obstruct the light issuing from the envelope. Therefore, a wire wound helically around the envelope is used or a continuous strip of metal covering about 1/5 of the envelope. The auxiliary electrode should be connected to earth through a finite impedance, *i.e.*, such a one that the starting would be less satisfactory if the impedance were much higher or lower, or through a low impedance which is interrupted for starting the discharge. Experiments proved that the helical electrode is more effective than the strip, that a resistive impedance is more effective than a capacitive one and that the interruption of the earth connexion is more effective than either. Any interrupter may be chosen for the purpose, but one operating by electrostatic attraction was found to be particularly suitable. It consists of two metal strips separated by a thin sliver of mica. One of the strips is earthed, the other is connected to the auxiliary electrode, and, through a high resistance, to an unearthed main electrode. When the voltage is switched on the strips attract each other and touch, thereby earthing the

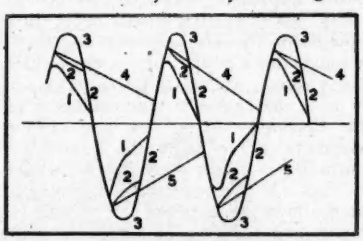

Fig. 13. Waveforms of discharge lamp in operation.

auxiliary electrode. The resistance causes a voltage drop, the strips separate again, and this cycle is repeated continuously. Although this is a much simpler arrangement than the valve oscillator it has still movable parts which occasionally might lead to trouble.

Patent 523839 of G.E.C., Ltd., and Pirani (1939) discloses the final step which does away with this interrupter and thus fulfils perfectly one of the most important principal requirements mentioned above. The auxiliary electrode is again arranged inside the tube and consists of two equidistant wires extending side by side throughout most of the space between the main electrodes. At least one of the wires, but preferably both of them are connected through a condenser to the main electrodes as shown in Fig. 12. Near the main electrodes the auxiliary wires are protected by suitable shields against the direct impact of electrons issuing from the main electrodes. A capacity of 1 μF is sufficient for the condensers. The arrangement of these auxiliary electrodes ensures that at all times and in all parts of the tube, ions are present, and especially before the main discharge reaches its striking voltage. The latter is as we saw also influenced by the gas pressure. The use of argon at 2 mm. pressure proved to be appropriate.

The glow discharge between the auxiliary electrodes is mainly perpendicular to the tube axis and this ensures that a sufficient number of ions strike the wall for neutralising the negative wall charges. Besides there is a voltage residue between the auxiliary and the main electrodes when the main voltage passes through zero. This may be realised by inspecting the oscillograms of Fig. 13, in which 1 is the voltage between the auxiliary electrodes, 2 the voltage between the main electrodes, 3 the supply voltage, 4 and 5 the voltage between the auxiliary and the main electrodes. (These curves only show the trend of the voltage curves, but do not give their correct phase relations.)

Fig. 14 shows the actual design of a tube with auxiliary electrodes. In order to support these electrodes the two wires are wound about 6 mm. apart in the same direction helically around a glass tube of about 5 mm. diameter, which at the same time at either end is used as a shield against electron impact from the main electrodes. This is accomplished by leading the wires of the auxiliary electrodes for some distance inside the supporting tube, as shown in the figure. The cylindrical shields around the main electrodes serve for protecting the ends of the main tube against blackening.

It was found useful to activate the wires forming the auxiliary electrodes by a coating of 99% BaN_3 and 1% CSN_3 at their central parts. In the tests the main tube had a diameter of $1\frac{3}{8}$ in. and a length of 20 in.

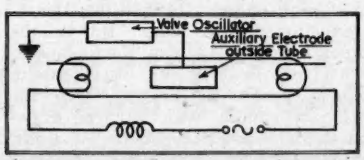

Fig. 11. Starting circuit using a valve oscillator

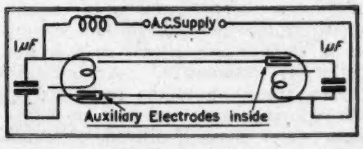

Fig. 12. Starting circuit with inner auxiliary electrodes and condensers.

One question should be discussed before we leave the subject of initiating and maintaining the glow discharge. While it appears obvious how ionisation occurs within the tube by a high frequency discharge applied to the auxiliary electrodes, it is not quite as obvious how the very first step of ionisation is brought about by arrangements as described in patents 517253 and 523839. As is shown by oscillograms, every few seconds voltage surges with a very steep front occur within the tube without any conceivable cause, the effective current of these surges being of the order of 10^{-6}a and the crest voltage about 300 v. It appears highly probable that these irregular surges and other less effective surges occurring with some regularity, but with smaller amplitude, are caused by cosmic rays and that these are therefore responsible for the first start of ionisation.

Transition from Glow to Arc Discharge.—We shall now deal with the second problem, the transition from the glow discharge to the arc discharge. Every engineer conversant with mercury arc rectification knows the problem of back-firing which occurs if the anode at any point of its surface is converted into a cathode, by some kind of impurity adsorbed on it. With the discharge lamp as we have seen, the electrode acts as a cathode and as an anode alternatively and it is the anode fall which keeps the electrode at the high temperature required for safe operation. So it may be said that the dreaded back-firing effect is turned here to good account.

The activated electrodes hitherto known consisted either of a metal wire coated with oxides or they were so-called "block electrodes" consisting of a conducting mixture of metal and oxide, or an internally heated nickel container was coated with oxides." The new electrode described in patent specification 537826 of G.E.C., Ltd., and Pirani (1940) consists of a cylindrical pellet placed inside a helical tungsten wire. The pellet consists of a mixture of barium chromate ($BaCrO_4$) with a reducing agent such as silicon, zirconium, tantalum, ferro-titanium or manganese-titanium. The barium may be replaced by calcium or strontium and the chromate by the aluminate. The reducing agent should not be too volatile and should be in considerable excess so that the pellet is conductive. A binder is chosen according to the reactivity of the reducing agent and may be potassium water glass if silicon, or ethyl cellulose if zirconium, is used as a reducing agent. The pellet should be porous and its surface rough so that the reduced metal may wander slowly to the surface, and so as to cause the glow discharge to concentrate on a few spots forming hot spots on the wire helix which is thus coated with a very thin, probably monatomic, layer of metallic barium. This has a very low work function (about 1 v.). It is essential that the layer is formed and replaced very slowly as otherwise the barium content of the pellet would soon be exhausted and the life of the electrode would be too short. In order to rely not entirely on the surges caused by cosmic rays for the initial ionisation, a tiny amount of a radio-active compound, *e.g.*, 0.01g of U_3O_8, was added to some of the pellets; but it is very likely that such an addition is not necessary.

With this kind of electrodes—with or without U_3O_8—in combination with an auxiliary electrode described above (Patent 523839) in a tube about 16 in. long and about $\frac{3}{4}$ in. diameter, filled with argon at a pressure of 10 mm. and a drop of mercury, and with the series impedance adjusted so as to carry 300 mA with 80-100 v. in full operation, the starting was regularly achieved on a supply of not more than 200 v. a.c. It was quite unnecessary to heat the cathodes independently of the discharge or to use any circuit elements other than the impedance normally in series with the discharge.

Thus all the requirements enumerated above are fulfilled. It should be mentioned that the object of dispensing with a special starter has apparently also been achieved by some development made in France, based also on the use of a special kind of the Wehnelt cathode. But A. Claude's publication on this achievement[11] gives only the names of the scientists instrumental in the solution of the problem (M. Bethenod and M. Lecorguillier) without stating in detail how it was actually solved. Due to present conditions the respective patent literature is apparently not available here so that we must confine ourselves to these brief indications.

Future Development.—The question is frequently asked whether the fluorescent lamp could not be modified so as to be readily installed with the outlets now in common use. No doubt this would materially facilitate the introduction of this lamp. But on the other hand the bulb of the incandescent lamp in present use shows in many ways its descendency from the ordinary candle with all the drawbacks of a pointlike source of light, and tubular lamps arranged along, or in recesses of, the edges of the ceiling have been used for many years as "strip lights" with stretched filaments and have given great satisfaction not only to the illuminating engineer, but also to the user. When new houses and settlements will be built after the war it will be advisable to make the fullest use of this beautiful and economic source of light and to lay out the wiring and the outlets so as to conform with its requirements.

That steps in the direction of modifying the lamp for its being used with ordinary outlets are under consideration is for example proved by French Patent 837795 (Philips) which describes various forms of tubes bent into some circular shape more suitable for domestic lighting.

Another question which has been asked lately is whether the higher economy obtainable by the fluorescent lamp should be utilised for reducing the current consumption with an equipment giving about the same illumination as with incandescent light, or for obtaining better lighting. The obvious answer to this question, as far as this country is concerned, is that under the present conditions of coal shortage the former tendency is surely preferable. In time of peace very likely there will be a change and a higher objective level of illumination than is practicable with incandescent lamps will then be set. This at least would be in accordance with the experiences made 40 years ago at the transition from the carbon filament lamp to the high efficiency tungsten lamp.

Rejuvenating Dry Cells

In the October issue of our contemporary, *Electronics*, M. E. Kennedy describes a successful method of extending the useful life of dry cells by re-charging them like accumulators.

A direct current of 150 mA. is passed through the cell for four hours or longer, the current being maintained constant throughout the charge.

A voltage-stabilising period of about six hours should be observed following the charge, the cell returning to normal voltage during this time.

Life tests on reclaimed cells show that it is possible to repeat the reclamation process about four times on the better grade of dry cell. Best results were obtained from fresh cells expended over a period of two weeks and reclaimed before they were entirely dead. It is essential that cells for reclaiming should have sufficient internal moisture in the electrolyte.

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CORRESPONDENCE

Controversy

SIR,—While agreeing with the implications in your Editorial of October that the best results may be expected from shoemakers who stick to their lasts, I think electronic engineers may thank Mr. T. Robson and Mr. D. R. Carling for drawing attention to a defect which is too common in our products.

That there are electronic experts who are also engineers, is clear from certain sound and robust designs, of which automatic traffic controllers may serve as an example.

But, it may be noted, these are usually made by firms with an engineering tradition based on the manufacture of heavy switchgear and similar equipment.

Now, a large proportion of our electronic engineers have been recruited, like the writer, from those who were "good at the wireless" in the heyday of amateur construction.

Numbers of such men have developed into what can, in every sense, be termed electronic experts. But, unless circumstances have combined to give them also some adequate mechanical training, many still fail to appreciate the very large difference between what will serve as a laboratory lash-up, or even as a finished domestic product such as a radio receiver, and the constructional standards necessary for reliable performance under industrial conditions.

The writer is in charge of the electronic laboratory of a firm of mechanical engineers, and during the past five years, a variety of technicians, and of equipment, has passed through his hands.

No names, no pack-drill, but, oscilloscopes being a feature of the original controversy, an example may be quoted of a C.R.O. for laboratory use only, which has been out of service six times since it was purchased less than a year ago.

To criticise the performance of such apparatus under heavy industrial conditions would be meaningless, since, clearly, it does not approach the standard necessary.

The need, however, does exist for reliable heavy-duty equipment, and lacking a satisfactory source of supply, we have been compelled to make our own, an uneconomic policy which we shall be only too glad to abandon, as soon as firms specialising in electronic devices market suitable apparatus, designed by electronic *engineers*.

Yours faithfully,

F. CAMPBELL ROSE.

NOTES FROM THE INDUSTRY

R.C.A. "Radio Nails"

The "tacking" of plywood, plastics and other industrial materials with "radio nails"—an almost instantaneous method of spot joining thin sections of material—is made possible by one of the newest electronic developments of the Radio Corporation of America.

The so-called "radio nail" is a discharge of high-frequency electric current which can be directed through a sheet of material, generating a quick and intense heat in its path. When two sheets of material are placed together with a coating of plastic glue between them, heat thus induced can be used to form a bond at the point of application.

The "radio nail gun" or spot gluer which R.C.A. has developed is an experimental device which has not as yet been offered commercially, but its operating principles bear promise of varied industrial usefulness, according to R.C.A. One field use now foreseen, for example, is in the fitting together of thin veneers in the manufacture of moulded plywood aircraft parts.

Resembling a short-barreled automatic pistol or a narrow-based electric flatiron in the two styles thus far designed, the "gun" or applicator is attached by a cable to a portable radio-frequency generator. Manœuvrability is enhanced by the use of a principle which makes it possible to locate both electrodes in the "muzzle" of the gun, whereas earlier dielectric heating devices have required passage of the material to be heated between two electrodes.

In the spot gluer, a pin extending lengthwise down the centre of the barrel forms one electrode, while the casing of the barrel is the other. In operation the muzzle is pressed against the material over the spot to be bonded and the current is applied by pressing the trigger. Since the material to be bonded is a better conductor than the air between the pin and the casing of the barrel, the current, following the line of least resistance, between the electrodes, follows a curved line through the material.

To permit some variation in the degree of fastness or permanency of the original bond, the spot gluer is equipped with an electronic timer which can be set to control the interval of application. The spot gluer has an output of approximately 50 watts and an operating frequency of about 200 megacycles.

Institute of Physics

X-Ray Analysis Group

The Board of the Institute of Physics has approved the formation of an X-ray Analysis Group. The object of the group is to provide a meeting ground for those interested in the theory and practical applications of X-ray diffraction; it is intended to arrange lectures, either independently or in conjunction with other bodies, and otherwise to promote contact between those using X-ray diffraction methods.

Membership of the Group is open (without payment of further fee) to all Fellows, Associates, Subscribers, and Students of the Institute of Physics. Specific application for enrolment as a member of the Group should be made to the Honorary Secretary, X-ray Analysis Group, Crystallographic Laboratory, Free School Lane, Cambridge.

Kolster-Brandes, Ltd.

We are informed that the recent notice in the technical press referred to Kolster-Brandes, Ltd., which went into voluntary liquidation on May 2, 1938, and not to the present company. An ambiguity in the wording has led to the assumption that the present company is in liquidation, which is definitely not the case.

Multi-core Solders, Ltd.

The address of the Head Office of this Company is now Commonwealth House, New Oxford Street, London, W.C.1. 'Phone CHAncery 5171/2.

E. K. Cole, Ltd.

Mr. N. C. Robertson, works manager since the war, has been appointed a director of the firm, together with Mr. A. G. Allen. Mr. A. W. Martin is now chief engineer. Mr. Martin has been with the firm since 1928 and as assistant chief engineer has been responsible for many technical and design developments.

Reliance Manufacturing Co.

Mr. J. B. Langley

We very much regret to record the death of Mr. J. B. Langley, co-director with Mr. J. R. Spink, of Reliance Manufacturing Co.

Mr. Langley joined the company over twenty years ago, and at the time of his death was technical director.

Those who had the pleasure of meeting him in either a technical or business capacity were impressed by his courtesy and friendliness, with which was associated first-class ability. His death is a loss to the industry, and we offer our condolences to his relatives and fellow workers in the company.

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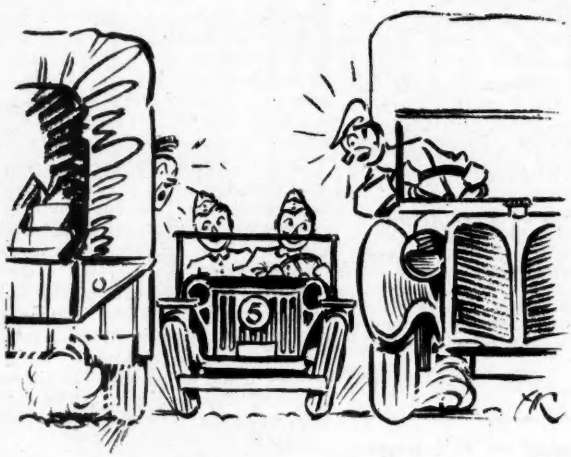

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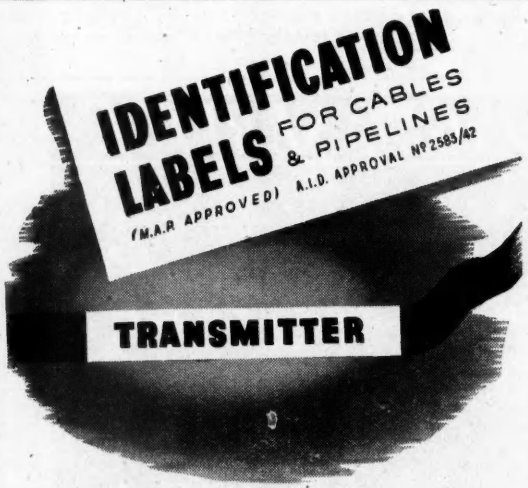

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BOOK REVIEWS

General Electrical Engineering

Edited by R. Kemp, M.Sc. (Odhams Press Ltd. 6s. 6d.net. 448 pp.)

The sub-title of this book is "A Comprehensive Introduction for Students, Apprentices, and all connected with the Electrical Engineering Industry."

Commencing with an elementary explanation of electricity and the electron theory, the chapters deal with simple apparatus and measurements, generation and transmission of power, installation work, and the applications of electricity. Two final chapters are concerned with telegraphy and telephony and radio communications and television.

There is an interesting practical note on electrical engineering drawing and a short glossary of terms in the appendix.

As is usually the case, this book has been compiled from chapters written by various experts in the different branches of the subject, and the material has been cleverly assembled to give a good general survey of the field. It is natural that gaps should occur, as presumably the board of contributors do not have an opportunity of comparing notes, and there are one or two places where a previous knowledge on the part of the reader is unjustifiably assumed (p. 41, for example, mentions a tangent galvanometer without describing its principle).

In the section on telephony it is disappointing to find the subject of Automatic Telephony dismissed in 80 lines and one diagram, but this is more than compensated for by 7 pages on joints and jointing.

The whole work is well illustrated and should stimulate newcomers to the industry to find a congenial subject in which to specialise after the war.

4,000 Years of Television

R. W. Hubbell 244 pp. (G. P. Putnams' Sons, New York. $2.25.)

"The story of seeing at a distance" describes the fundamental principles and development of television in a popular style from the age unrecorded history to the time of the public service from Alexandra Palace.

The story commences in 2,000 B.C. with the discovery in Assyria of the knowledge of optics, continues to the discovery of magnetism in Magnesia, amber in Greece and then on to the work of William Gilbert in 1600 A.D. The inventions are given in order of appearance until the stage is reached when, by merging the many details, practical experiments could be undertaken.

John L. Baird's progressive work is ably described, and it can be realised how many were the contributions he made towards the perfection of television. The chapters covering developments of the last ten years include the achievements of the public service from Alexandra Palace, the experimental work in America by Drs. Zworykin and Goldmark, and the strides made in colour television in England and America. The fateful 1939 when A.P. closed down is vividly recalled.

An interesting chapter "Mystery Weapons," shows how the many inventions which combined to make television a possibility, may be diverted to the requirements of war.

The book is excellently written in a most entertaining fashion, and is recommended as interesting reading to the engineer as well as to the semi-technical viewer.

D. A. P.

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For other bargains see previous advertisements.

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Classified Announcements

The charge for miscellaneous advertisements on this page is 12 words or less 3/-, and 3d. for every additional word. Single-column inch rate displayed, £1. All advertisements must be accompanied by remittance. Cheques and Postal Orders should be made payable to Hulton Press, Ltd., and crossed, and should reach this office, 43, Shoe Lane, London, E.C.4, not later than the 15th of the month previous to date of issue.

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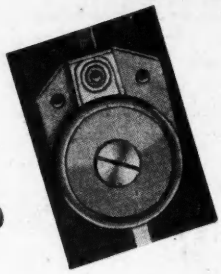

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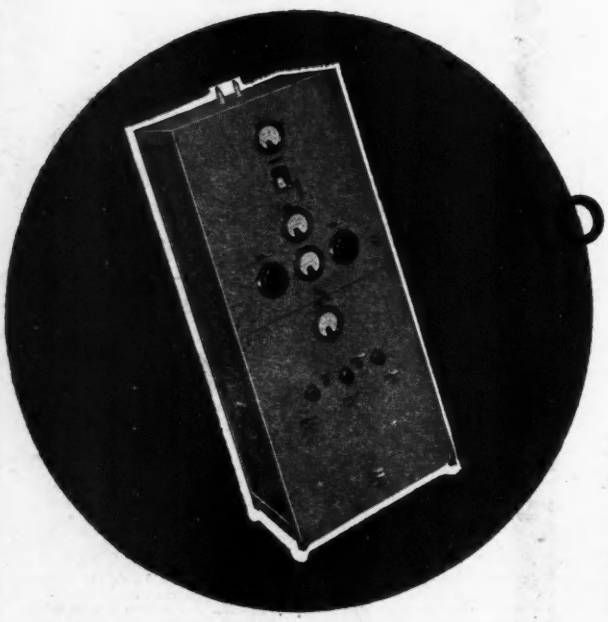

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